solar energy feasibility study
at the
san francisco international airport

[Final Report]

prepared for
the airports commission
of
the city & county of san francisco
california

by
interactive resources, inc.
with
gayner engineers
ayres associates

Solar Energy Feasibility Study

at the

San Francisco International Airport

Prepared for

The Airports Commission of
The City and County of San Francisco
California

by

Interactive Resources, Inc.
Point Richmond, California

with

Gayner Engineers
San Francisco, California

and

Ayres Associates
Los Angeles, California

September 1977

Interactive Resources, inc.
comprehensive professional services group

Thomas K. Butt, AIA
John E. Clinton, AIA SE
Dale A. Sartor
James C. Beavers
Charles L. Beavers
Carlos D. Garza
Suzanne E. Bean
Shirley R. Butt
Thomas N. Campiglia
Edward C. Love
Carl H. Bovill
E. Burr Nash
F. Thomas Collins, CE ME
George R. Teiber
Margie Tims
Karen M. Fee
John L. Peterson, ME

27 September 1977

Airports Commission
City and County of San Francisco
San Francisco International Airport
San Francisco, CA 94128

Attn: Mr. Robert G. Lee
Deputy Director and Chief Engineer

Gentlemen:

Attached is the final report which summarizes the results of our Solar Energy Feasibility Study for the San Francisco International Airport.

Bound separately in an appendix are sections 2 through 5 which elaborate on the content of this report.

We are prepared to proceed with the detailed design of any of the project components and assist you in preparing grant applications for federal funding.

Sincerely,

INTERACTIVE RESOURCES, INC.

Dale Sartor

Dale Sartor

DS/sb
enclosure

117 park place point richmond, ca. 94801 (415)236-7435

Table of Contents

List of Tables

List of Figures

Appendices (bound separately)

1.1 Introduction

Because of an estimated total roof area of 584,000 square feet potentially available for locating solar collectors, the Airports Commission conceived this study as a logical extension of an existing energy conservation operating and maintenance policy. On 15 June 1976 the Airports Commission of the City and County of San Francisco adopted a resolution directing the Director of Airports and staff to

> ....investigate and make such studies as necessary on the feasibility, applicationand use of solar energy at San Francisco International Airport and...to investigate the possibility of applying for any state or federal demonstration grants available for this purpose.

A request for proposals was issued on 24 June 1976 and Interactive Resources, Inc., was subsequently selected from some 21 respondants to perform the feasibility study. A contract was executed on 21 December 1976 and a notice to proceed with work issued effective 7 February 1977.

There are virtually unlimited opportunities to reduce energy consumption at the airport. It is the purpose of this report to evaluate the potential and feasibility of offsetting the dependence on outside fuel sources with the use of solar energy, and secondarily to assess additional energy conservation options.

1.2 Recommendations

Based on the results of the study, it is determined that the use of solar energy at the airport is practical for domestic water heating and passive space conditioning. Pilot projects should be built prior to a large scale commitment to fully develop materials, equipment and operating techniques peculiar to the requirements of the airport.

It is therefore recommended that:

a. The airport should apply for federal funding to install solar domestic hot water heating systems on Rotunda A, Piers H and I and the North Terminal.

b. Water meters should be installed in several locations to confirm the estimates of domestic hot water usage and time of day trends.

c. A comprehensive computer simulation study of the airport's energy use should be prepared and applied to optimization studies prior to making any significant decisions regarding modification or implementation of energy conservation strategies.

d. The airport should apply for federal funding to install an integrated passive solar space conditioning system including optimized solar shades, ceiling fans and increased thermal mass in Piers H and I.

e. The airport should consider and implement the additional energy conservation measures enumerated in this study.

1.3 Results of the Feasibility Study

a. In order of descending technical feasibility and cost-effectiveness, solar energy may be used now for:

(1.) domestic hot water heating, and
(2.) space heating.

b. Developing technologies which may have potential applications in the near future are:

(1.) solar-assisted central boiler;
(2.) solar absorption air conditioning;
(3.) solar heat engines;
(4.) solar-assisted total energy system; and
(5.) photovoltaic cells (direct electrical production).

c. The airport should apply for federal funding to install solar domestic hot water heating systems on Rotunda A, Piers H and I and the North Terminal. This would require 5,360 square feet of flat plate solar collectors and 9,550 gallons of hot water storage which will provide 16,000 therms per year or 43 per cent of the water heating load (in these locations) at an installed cost of $227,200. These three locations were chosen because they are not scheduled for remodeling in the near future.

Federal funding for solar systems is available competitively through the federal solar demonstration programs. The airport would qualify under the ERDA (Energy Research and Development Administration) commercial demonstration program. A solicitation for the third cycle should be issued soon with proposals due by the end of 1977.

d. Installation of water meters to measure actual hot water usage at strategic locations (typical use areas that could be utilized to project overall usage) would vastly improve the information on which the recommended solar domestic hot water heating systems would be designed.

e. A sensitivity analysis showed the overwhelmingly positive influence of time on the economic value of the systems, while higher initial costs showed a relatively small impact on long-term value. This suggests that extra initial costs which add to the life of the system are well spent. Also, a system that can survive the inevitable remodeling that the airport experiences would realize much greater returns.

f. Glare off the collectors interfering with the air traffic controllers' view is a potential problem, and the Federal Aviation Administration will want to judge on the matter before a solar system is installed. Because of the collectors' mounting angle (35° from the horizontal) and the distance between the collectors and the control tower, most of the potential collector locations will reflect their glare well over the heads of the air traffic controllers and therefore will not cause a problem.

g. Installing metal solar collectors on the terminal and pier roofs could interfere with the instrument landing system. There is probably enough steel in the buildings such that adding a little more metal on the roof will not cause any problems. The FAA will want to judge on this matter also before a solar system is installed.

h. Active solar energy utilization is more expensive at the airport than at comparably-sized, privately-owned facilities and is a borderline economic investment; however, secondary and indirect benefits may be valuable trade-offs.

i. Many energy conservation measures may be significantly more cost-effective than solar applications. However, potential outside funding sources may mitigate this conclusion.

j. The airport should apply for federal funding to install an integrated passive solar space conditioning system in Piers H and I. The system would include optimized solar shades; ceiling fans and increased thermal mass, and may include roof monitors and/or additional ventilation. Detailed computer modeling will be required to optimize the system design. Piers H and I were chosen because of their fixed design and skin-dominated loads.

k. A comprehensive computer simulation study of the airport's energy systems should be prepared and applied to optimization studies prior to making any significant decisions regarding modification or implementation of energy conservation strategies.

1.4 Scope of Work Completed in this Study

a. Estimates of yearly, monthly and hourly heating and cooling loads checked against actual utility records where applicable.

b. Inspection of the existing facilities, review of the drawings and specifications for the North Terminal and Piers H and I, and review of the master plan for airport modernization and replacement.

c. Investigation of potential solar collector locations and consideration of special problems associated with glare and radar interference.

d. Schematic designs for water, space and combined heating systems for each area of the airport, including interface with conventional equipment.

e. Review of applicable solar components and systems.

f. Preliminary selection of appropriate key solar components.

g. Preliminary cost estimates.

h. Computer simulations to optimize the solar water and space heating systems, estimate thermal performance, and analyze the economics (life-cycle costs).

i. Sensitivity analyses of key variables used in the simulation, including collector tilt, area and efficiency; fuel cost and escalation; life-cycle (number of years) and system costs; and maintenance costs.

j. Investigation of passive solar utilization, including natural lighting, shading and methods of increasing the thermal mass (thermal storage).

k. Review of more exotic (expensive) solar applications, including air conditioning, central plant heating, electrical production and total energy systems.

l. Identification and investigation of conservation options that may be more cost-effective than solar applications.

m. Investigation of funding sources.

1.5 Alternative Approaches to Energy Conservation

a. Active (mechanical) solar energy applications. The principal thrust of this study is an analysis of active (or mechanical) solar energy utilization (see Appendix, Section 3). An active solar system includes a collector, either flat plate or concentrating, a storage medium and a mechanical distribution system. Active solar systems are in wide use for swimming pool heating, water heating and space heating and, to a diminished degree, for space cooling. Solar/mechanical and solar/electrical production are in the developmental stage.

b. Passive (architectural) solar energy applications. Section 4 of the Appendix centers on another less obvious but important opportunity for solar energy utilization. Any building is a solar collector, but the control of heat gain and light, storage and distribution (with architectural elements) is the challenge. Orchestrating these design elements to optimize the interaction of the site's microclimate with occupant comfort and building function has come to be known as "passive" solar utilization.

For example, considering the temperate climate of the airport and the internal heat generated by occupants, lighting and mechanical equipment, little or no heating should be required. Similarly, good ventilation and proper window shading will minimize the cooling requirements. In the San Francisco climate, a well designed building should require little energy for heating and cooling. Balancing the monthly heat gains and losses and increasing the thermal mass to promote a flywheel effect can maximize the passive use of solar energy for natural lighting, heating and cooling.

c. Modification of existing and proposed electrical and mechanical systems. There is a danger in considering solar energy itself as a method of energy conservation. Even though the source is free and inexhaustible, scarce and expensive resources are still required to convert it for useful purposes. Reducing the total requirement for energy is generally less expensive in terms of money and resources than alternative means of supplying that energy. Section 5 of the Appendix includes an analysis of energy conservation opportunities related primarily to existing and proposed electrical and mechanical systems.

1.6 Recommended Priorities for Energy Conservation

The energy conservation alternatives studied have been divided into four categories in descending order of apparent economic and technical feasibility. It should be noted that only active solar applications in this study received full and detailed life-cycle cost analyses. Nevertheless, some conservation options are so cost-effective that the advantage of timely implementation is obvious. Other apparent opportunities would require extensive computer modeling for accurate analysis, and their ranking is based largely on experience and intuition. All energy savings and cost projections are estimates and not guarantees. Detailed descriptive and cost information for the various recommendations can be found in Sections 3, 4 and 5 of this study, bound separately as an appendix.

The introduction of outside funding (see Section 1.9) could substantially change the economic attractiveness of various alternatives and has, for example, changed solar water heating from a relatively low Category C to a relatively high Category B.

a. Recommended for immediate implementation

Lighting. Reducing the lighting load by increasing efficiency and reducing levels will save energy in two ways. First, by reducing the electricity used for lighting and, second, by reducing the heat associated with lighting and the corresponding cooling requirements. Wattage of both fluorescent and incandescent lamps should be reduced during normal relamping at little or no additional cost. Whenever ballasts are replaced, more efficient units should be substituted. Artificial lighting in the terminal lobbies and in the piers can be reduced or eliminated during daylight. For example, turning off half of the main lobby lights in the South Terminal for 10 hours per day would reduce the lighting levels about 10 to 15 per cent and would save close to 200,000 KWH per year, or over $5,000. Automatic switches controlled by photo cells should be installed to ensure adequate lighting levels and maximum utility savings. Lighting levels in certain areas can be reduced permanently. The potential annual energy savings due to conservation in lighting is 2.5 million KWH.

HVAC controls. Improper calibration and operation of controls including leaking and frozen dampers can account for sizable energy inefficiencies. All controls should be carefully checked and calibrated. A thermostat strategy should be established to slightly expand the comfort range to save heating and cooling, i.e., heating at 65-68°F. and cooling at 78-80°F.

Static Pressure Losses. The air systems in the North Terminal, Piers H and I and Rotunda A have high velocity duct systems ranging from 6.5-inch to 11-inch static pressure losses as compared to 3.5-inch in the Central and South Terminals. Such high pressure systems are energy-intensive and can be improved by reducing the air quantity and/or reducing the mechanical losses through the air filters. A 10 per cent reduction in air quantity would reduce motor horsepower 35 per cent and would save over 2.7 million KWH annually, Removing a portion of the filters would increase maintenance and lower air quality but could save 1.8 million KWH per year due to reduction in static pressure.

Motors. Small motors being replaced or installed can be replaced with more efficient, longer life units at slightly higher costs.

Garage Exhaust. Supply fans in the new garage are controlled by carbon monoxide monitors. Exhaust fans can also be controlled in this fashion (currently they operate continuously). With the strong prevailing winds and cyclical nature of the garage traffic, automatic exhaust controls could save 50 per cent or 300,000 KWH per year.

Domestic Water Temperature. Domestic water temperature in the new North Terminal and Piers H and I is already set at 105°F. We recommend that the water temperature in the existing terminals and piers be reduced from 140°F. and future remodeling also be designed for 105°F. Lower water temperatures conserve energy by reducing heat loss and facilitate solar interface.

Water Use. Water conservation saves energy in pumping, treating (supply and waste) and heating for domestic hot water. Flow restrictors and other water-saving devices should be considered.

Window Size. Windows in the existing airport complex are generally four to five feet in height. Windows now being installed in the North Terminal and Piers H and I are approximately 10 feet high (floor to ceiling). Windows account for the greatest heat lost from the skin of the building and when poorly oriented and/or shaded account for a sizable portion of the unwanted heat gain (cooling load). We recommend that windows be reduced in size and that those installed be optimized for view, natural light and thermal efficiency. Initial cost is, of course, less for smaller window areas.

b. Recommended for further study—high priority

Solar domestic water heating. Domestic hot water heating offers the best opportunity for an active solar application at the airport. The temperature requirements ($110^{o}F. \pm$) are low and easily achieved with relatively inexpensive flat plate collectors. The load is fairly consistent year 'round, thus minimizing thermal storage requirements and maximizing collector output. The system size can be optimized to provide a large percentage of heating requirements in summer but never an excess. Calculations indicate the optimum annual solar contribution to be about 43 per cent. Table 1.6.1 gives a summary of optimum solar system sizes, performance and cost for all the locations studied. Table 1.6.2 itemizes the estimated system costs as a function of collector area.

The airport should apply for federal funding to install solar domestic hot water heating systems on Rotunda A, Piers H and I and the North Terminal. Rotunda A will require 480 square feet of solar collector and 860 gallons of hot water storage which will provide 1,400 therms per year of water heating at an installed cost of $22,320. Piers H and I will require 2,850 square feet of solar collector and 5,140 gallons of hot water storage which will provide 8,500 therms per year of water heating at an installed cost of $117,350. The North Terminal will require 2,030 square feet of solar collector and 3,550 gallons of hot water storage which will provide 6,100 therms per year of water heating at an installed cost of $87,530. These locations were chosen because they are not scheduled for remodeling in the near future.

If funded entirely by the airport, solar domestic water heating would pay for itself in approximately 22 years. Total or partial funding with federal money from the ERDA demonstration program would considerably improve the economic picture.

As shown in Figure 1.6.1, the proposed system is a pressurized system in which potable water flows directly through the collectors. When the collector temperature is higher than the storage tank temperature, a pump is activated which circulates water from storage through the collectors and back to storage. As a water load occurs, hot water is drawn off the top of the tank. From there it passes through the existing heat exchanger, which will add more heat to the water if necessary, and then continues to its use point. The back-up heat exchanger is supplied with heat from the primary heating loop.

Installation of water meters to measure actual hot water usage at strategic locations (typical areas that could be used to project overall use) would vastly improve the information on which the solar domestic hot water heating systems were designed. For example, if the largest portion of the hot water load occurs during the day, solar storage volumes could be reduced, saving money and space.

Passive solar space conditioning. The airport should apply for federal funding to install selectively located solar shades, ceiling fans and increased thermal mass as described below. Each of these concepts alone will save energy and all together they constitute a well integrated passive solar system. Properly shaded windows allow sunlight penetration in the winter when heat is most needed but block solar radiation in the summer. Thermal mass absorbs excess heat and stores it for later use. The ceiling fans will reduce heat stratification and expand the temperature comfort range allowing excess heat generated by crowds of people to be gradually absorbed by the mass. Detailed computer modeling is required for optimizing a passive solar system of this nature. Theoretically, little or no mechanical heating or cooling will be required. If the computer simulation indicates additional heat requirements, then south-facing roof monitors as described below should be added. If additional cooling is indicated, then an outside air economizer as described below could circulate night-time air through the building to cool the thermal mass.

Although the concepts are simple, the engineering of passive solar systems integrated into complex environments such as the airport is difficult and somewhat experimental. Therefore, we are recommending that only Piers H and I which seemingly have a skin-dominated load (unlike the North Terminal which is dominated by internal loads) be initially considered as a pilot project.

Shading devices. Proper shading of windows is critical. Ideally, a shading device should allow for sunlight penetration during the heating season and shade the window during the cooling season. For windows facing south, this is easily accomplished with a simple overhang. Other exposures require other treatment, i.e., larger overhangs and/or vertical louvers.

A methodology is presented in Section 4 of the Appendix for analyzing the effect of any shading device for any orientation as it relates to the overheating period. Recommendations and analyses of generic types were made for various orientations. No attempt was made to assess cost or exact utility savings (the latter requiring computer modeling).

External and internal, permanent and movable shading devices were noted in use at the airport. Permanent external shades are preferred for reliability and efficiency. As it has done in the past with varying degrees of success, shading will reduce the requirement for cooling.

Ceiling fans. Thermostatically controlled, variable speed ceiling fans can save heating and cooling costs. At low speeds they cut heating requirements up to 30 per cent by minimizing temperature stratification (the difference between ceiling and floor temperatures). At higher speeds

(increased air velocity) ceiling fans have a cooling effect. The greatest cooling loads occur at the airport when crowds of people gather at one gate. Fans would delay if not eliminate the need for air cooling by allowing the temperature to rise while maintaining human comfort levels.

Increase thermal mass. Instead of wasting internal heat generated by people, lights and machinery, and the heat from solar gain (by operating an energy-consuming air cooling system) and thermal mass can be employed to absorb excess heat and store it for night time or later use. Increasing the thermal mass of a building with masonry, water or phase change materials will dampen or stabilize the effects of exterior and interior temperature fluctuations. For this strategy to work, the internal temperature must be allowed to fluctuate somewhat.

Insulation. Generally, insulation is a good investment and should be increased in the roof, walls and floors (over unheated spaces); however, the optimum amount has yet to be determined. In certain areas, insulation may be counter-productive: the internal heat generation from people, lights and machinery may exceed the heat losses requiring air conditioning, even with cool outside temperatures. The optimum insulation, if any, can only be determined with computer modeling of the airport through a typical year. The computer simulation accounts for all heat gains and losses and can be used to compare alternative architectural and mechanical strategies.

Roof monitors. North-facing (or shaded south-facing) roof monitors, perhaps located under active solar collectors, are recommended for natural lighting. Natural lighting is extremely efficient and pleasing to the eye. Artificial lighting converts only a portion of energy to light; the rest is converted to heat adding to the air conditioning load. Vertical monitors are easy to maintain, are glare-free, and save electrical energy used for artificial lighting and air conditioning. Double glazing and/or shutters are recommended to prevent excessive night time heat losses.

Outside air economizer. The existing HVAC systems in the Central and South Terminals including boarding areas have provisions for ventilating with outside air. The new North Terminal and piers have a limited fixed outside air intake. Often cool outside air circulating through the terminal could substitute for air conditioning; rarely is the airport's ambient temperature above the comfort range. Converting the North Terminal's mechanical system to a variable outside air intake dependent on the cooling load and outside temperature would save over four million KWH per year.

Ventilation. Natural ventilation has limited potential due to noise and air quality problems, but additional mechanical ventilation may be effective, especially in cooling the thermal mass of a passive solar system.

Program start-stop. The airport traffic is cyclical and could therefore save energy by shutting off some of the 363 fans during low-load periods. A reduction of only one hour per day of operation (excluding garage vent motors) would save 1.3 million KWH per year.

Automatic faucets. Automatic closing faucets should be considered to save water and reduce the corresponding energy required for heating.

Flue gas heat recovery. Commercially available economizer heating coils can be installed in the central boiler exhaust flues to capture waste heat for domestic water and/or space conditioning.

c. Recommended for further study—medium priority

Solar space heating. Due to the cool climate, 24-hour operation and, in some zones, a terminal reheat system, the airport has a space heating load year 'round. Therefore, like solar water heating, a space heating system can be optimally sized to provide a large portion of the summer time demand and only a small portion of the winter demand. Table 1.6.1 indicates the optimum solar system will provide 32 per cent of the space heating load in each zone.

A proposed solar space heating system is diagramed in Figure 1.6.2 which uses water both as the transfer and storage medium. When the collector temperature is higher than the storage tank temperature, a pump is activated which circulates water from storage, through the collectors and back to storage. As a heating load occurs, air is blown from the space through a heating coil which is supplied with solar-heated water. The air then is blown through an existing coil, now used as a back-up, which is supplied with water from the secondary heating loop. Heat to these coils would be controlled by a two-stage thermostat.

An alternative to this interface would be to use solar to preheat the secondary heating loop. This would mean converting the loop from the present variable volume system to a variable temperature system.

The storage tank in this system is unpressurized and water simply drains from the collectors back into the tank when the pump is off.

Solar heating the entire airport would cost over $5 million, as itemized in Table 1.6.1. If funded entirely by the airport, a space heating system would require 24 years to pay for itself. Although federal funding is feasible, the airport should not proceed with mechanical solar space heating until a pilot water heating system has been installed, and passive solar heating and other energy conservation options have been thoroughly considered.

Combination solar space and water heating. Space and water heating can be combined, sharing collection and storage facilities. A single collection and storage system will be less expensive and will allow for extra capacity in one distribution system when the other is not needed. The disadvantages are that both systems must operate at the same temperature and a heat exchanger is generally required for the domestic hot water, reducing system efficiencies.

A proposed combination system is diagramed in Figure 1.6.3. The collection loop operates exactly as in the space heating system. However, distribution is divided between space and water heating. As a space heating load occurs, air is blown through a heating coil which is supplied with solar-heated water. The air then passes through an existing coil, which serves as the back-up and is supplied with water from the secondary heating loop. As a domestic hot water load occurs, potable water flows through two heat exchangers. The first is supplied with solar-heated water from the storage tank. The second is the existing heat exchanger which serves as the back-up and is supplied with water from the primary heating loop.

The combination systems listed in Table 1.6.1, if funded entirely by the airport, will require 24 years to pay for themselves from fuel saved. Again, solar domestic hot water heating should have a higher priority of implementation.

Insulating glass. Insulating glass, like insulating walls, will save energy and increase comfort during the heating season; however, their overall effectiveness may be counter-productive where internal heat gains dominate heat losses and air conditioning is required. Again, only computer modeling will provide the optimum solution.

Automatic or remote peak power reduction. A system to automatically "shed" or turn off electrical demands on a pre-determined priority schedule will lower peak demand and utility cost. Presently the utility cost savings is small. However, utility pricing trends are clearly toward minimizing peak demands in order to reduce the need and subsequent capital expenditure for new power plants. A computerized load control system which could be programmed to turn off fans and other demands on a regular basis (at night, etc.) could cost over $1 million.

Conversion to variable air volume system. All of the existing and new terminals under construction use the constant volume air system for cooling, heating and ventilation. The air quantities delivered are based on block building peak loads for cooling. During much of the time, however, the building is operating at less than peak load and air quantities can be reduced without sacrificing comfort conditions. The reduction of air quantities during non-peak conditions will save energy by saving motor horsepower with the use of proper variable volume control devices. This also saves energy in cooling a smaller quantity of supply air and reheating air at some perimeter zones.

d. Recommended for further study—low priority

Central control and monitoring system. A master control system could be established in the airport complex. This system would take over the functions of the HVAC system control and monitoring, provide maintenance program functions, program start-stop of fans and motors, provide load-shedding to reduce peak electrical demand and also be able to supervise the fire alarm system, security system, guard tour route check and closed circuit television. The cost of such a system will be around $3 million.

Solar heating of primary loop with concentrating collectors. A portion of the energy consumed by the boiler can be displaced by utilizing high-temperature concentrating solar collectors which feed directly into the boiler at the central plant. Interfacing for this system would be relatively simple but the technology of concentrating collectors is not well proven yet. Figure 1.5.4 diagrams this system.

Solar absorption air conditioning. An absorption air conditioning system could be driven by a medium temperature (150-300^{O}F.) flat plate or concentrating collectors. The absorption chiller may be used to provide a cooling effect directly or to pre-cool water for an existing compressor chiller. The technology for doing this is in the developing stages. Figure 1.5.5 diagrams this system.

Solar heat engines. Another method of cooling utilizes solar heat to power a Rankin Cycle Turbine or other heat engine which then could be used to drive a compression chiller or electric generator. Concentrating collectors would be able to provide the high temperatures necessary to maintain an acceptable level of efficiency. The technology of solar heat engines is in its infancy. Figure 1.5.6 diagrams this system.

Solar total energy systems. The next level of overall system efficiency can be obtained through the utilization of a total energy system. This design uses the heat from high temperature concentrating collectors to drive a heat engine as in the above system. The engine is then used to drive either an electrical generator or a compression chiller. The "waste" heat from the heat engine is then used to either drive an absorption chiller or to feed the secondary space heating loops. The "waste" heat from the compressor or absorption chillers can also be used to provide domestic water heating. This approach is in the development stage and will require extensive design and engineering for each system application. This system is diagramed in Figure 1.5.7.

Photovoltaic cells. Photovoltaic cells are semiconductor devices that produce electricity directly from sunshine. The output of solar cells is DC electricity. Solar cells are expensive and presently are only cost-effective in remote locations.

Table 1.6.1

Solar System Size, Performance and Cost

(DHW = domestic hot water heating; Space = space heating.)

Location	Collector Area (square feet)	Energy Saved (therms/year)	Per Cent Solar	Storage Capacity (gallons)	Initial Cost ($1,000)
South Terminal					
DHW	1,898	5,600	43	3,416	78.19
Space	20,523	56,000	32	36,941	942.75
DHW and Space	23,841	65,300	34	42,913	1,078.47
Central Terminal					
DHW	3,470	10,300	43	6,246	144.81
Space	11,409	31,200	32	20,536	523.37
DHW and Space	17,259	47,400	39	31,066	760.37
North Terminal					
DHW	2,038	6,100	43	3,558	87.53
Space	28,000	77,000	32	50,400	1,296.67
DHW and Space	31,809	86,900	34	57,256	1,442.83
Piers H and I					
DHW	2,859	8,500	43	5,146	117.35
Space	14,628	39,900	32	26,330	671.92
DHW and Space	19,530	53,500	37	35,154	871.01
Pier B					
DHW	661	2,000	43	1,189	29.45
Space	4,441	12,100	32	7,993	204.05
DHW and Space	5,585	15,300	36	10,053	252.80
Pier C					
DHW	1,276	3,800	43	2,296	54.05
Space	4,441	12,100	32	7,993	204.05
DHW and Space	6,598	18,100	38	11,876	293.31
Pier D					
DHW	773	2,300	43	1,391	33.94
Space	4,441	12,100	32	7,993	204.05
DHW and Space	5,773	15,800	36	10,391	260.31
Pier E					
DHW	1,160	3,400	43	2,088	49.41
Space	4,234	11,600	32	7,621	194.35
DHW and Space	6,198	17,000	38	11,156	275.93
Pier F					
DHW	714	2,100	43	1,285	31.58
Space	17,569	47,900	32	31,624	807.06
DHW and Space	18,832	51,400	33	33,897	860.59
Rotunda A					
DHW	483	1,400	43	869	22.32
Space	11,502	31,400	32	20,703	528.36
DHW and Space	12,356	33,800	33	22,240	565.53

Table 1.6.2

Estimated Costs as a Function of Collector Area

(excluding fixed costs of interface)

	Dollars per Square Foot of Collector	
	Minimum	Maximum
Collector	$12.00	$14.00
Storage	2.00	4.00
Transfer loop	3.00	5.00
Subtotal	$17.00	$23.00
Subcontractor overhead (15-20%)	2.55	4.60
Subtotal	$19.55	$27.60
Subcontractor profit (10-15%)	1.95	4.14
Subtotal	$21.50	$31.74
General contractor overhead and profit (15%)	3.22	4.76
Subtotal	$24.72	$36.50
Bond (1%)	.25	.36
Total construction cost	$24.97	$36.86
Net capitalized interest during construction	.04	.04
Professional services (12.5%)	3.12	4.60
Subtotal	$28.13	$41.50
Cost escalation (12% per year, one year)	3.37	4.98
Subtotal	$31.50	$46.48
Contingency (5%)	1.57	2.32
Total	$33.07	$48.80

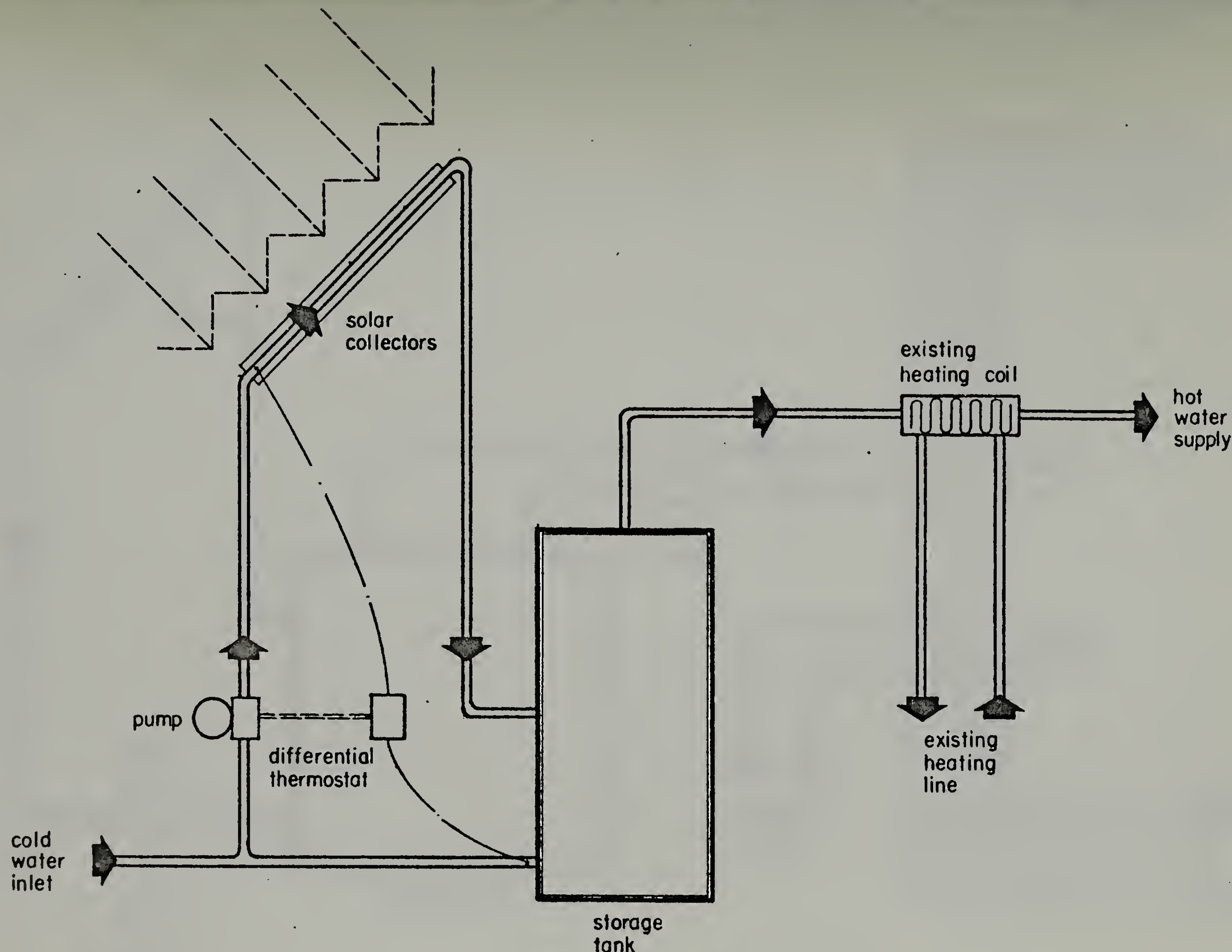
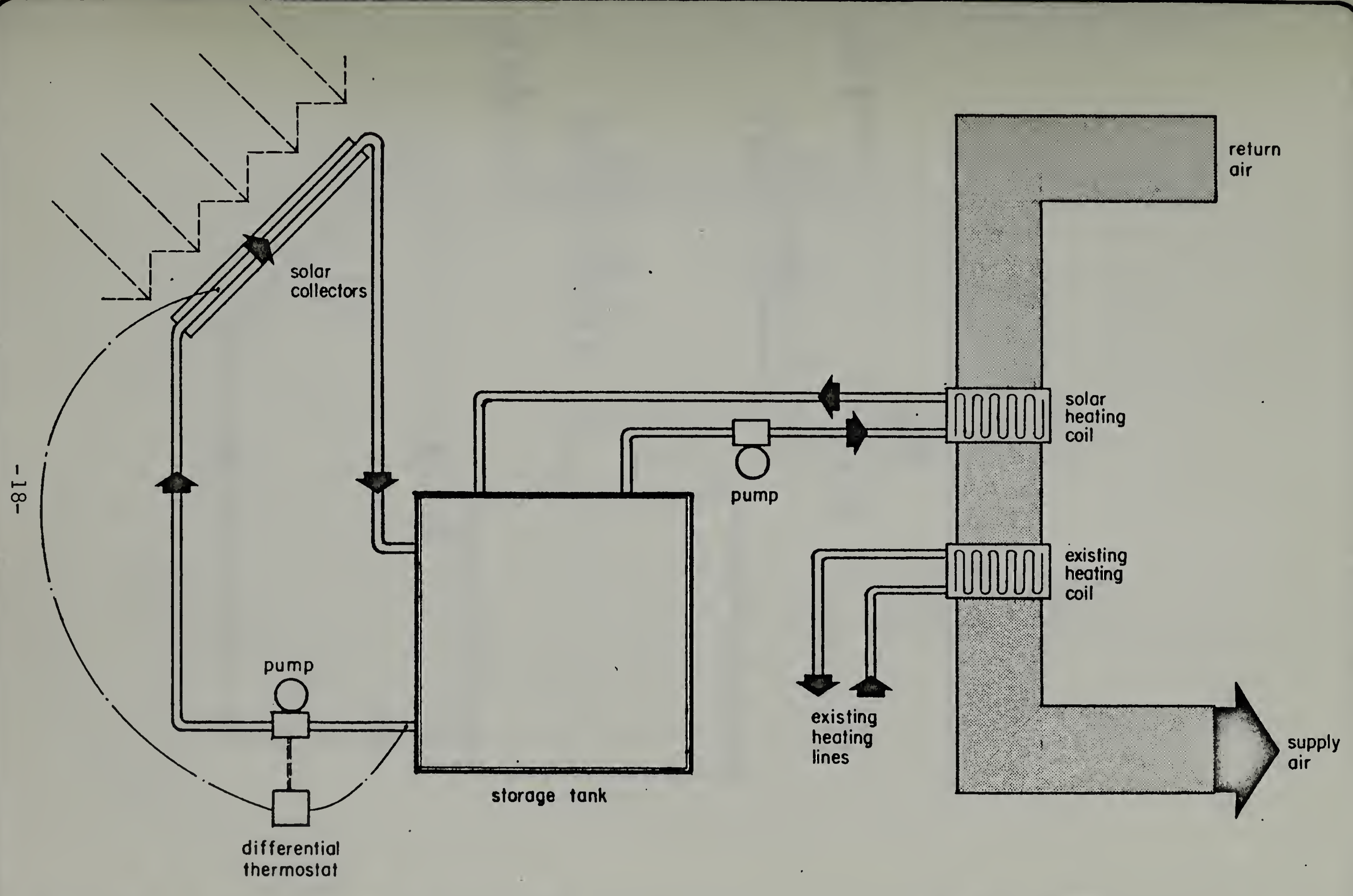


fig. 1.6.1

typical domestic hot water solar heating system



san francisco international airport

solar feasibility study

fig. 1.6.2 typical solar space heating system

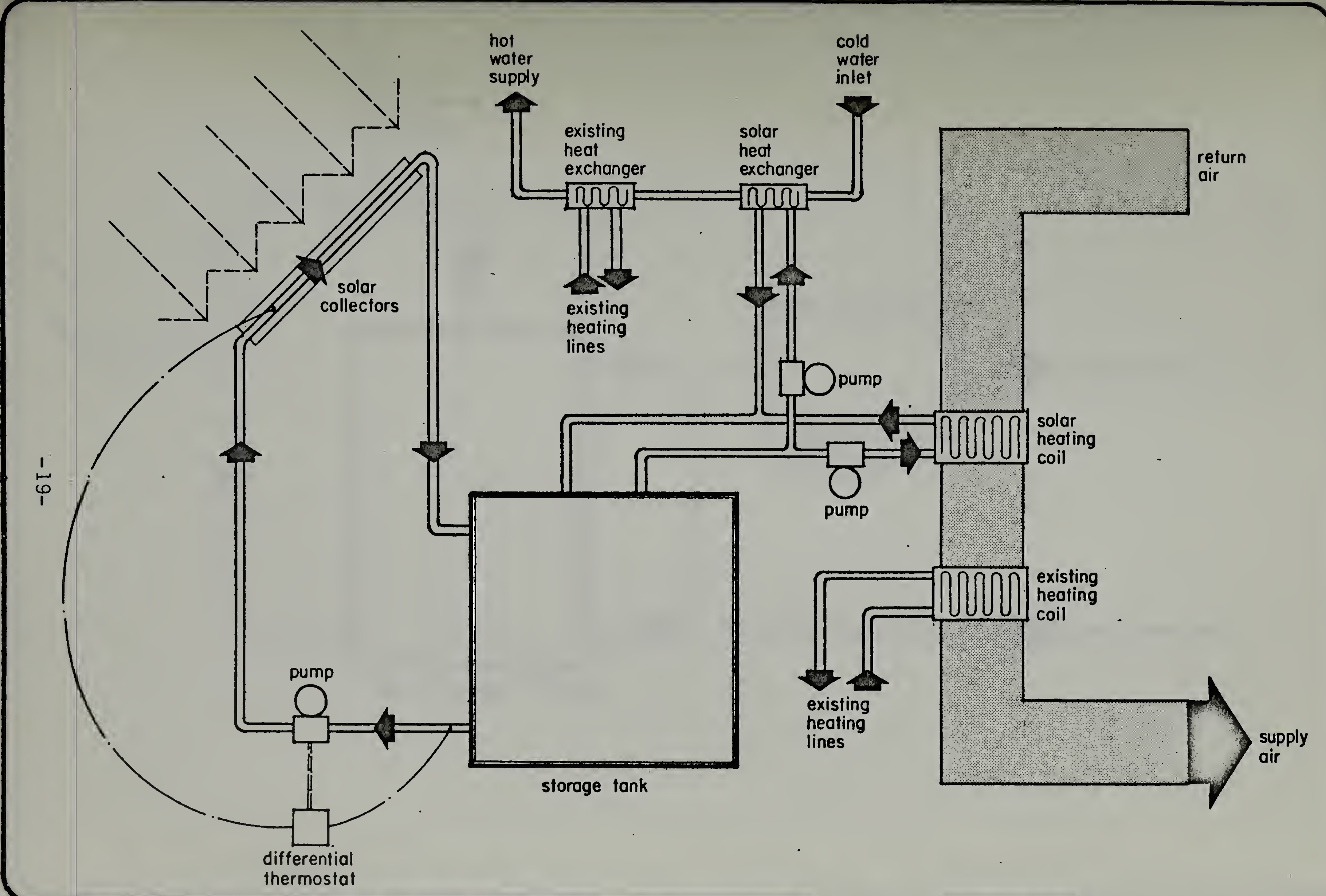


fig. 1.6.3 typical solar space and DHW heating system

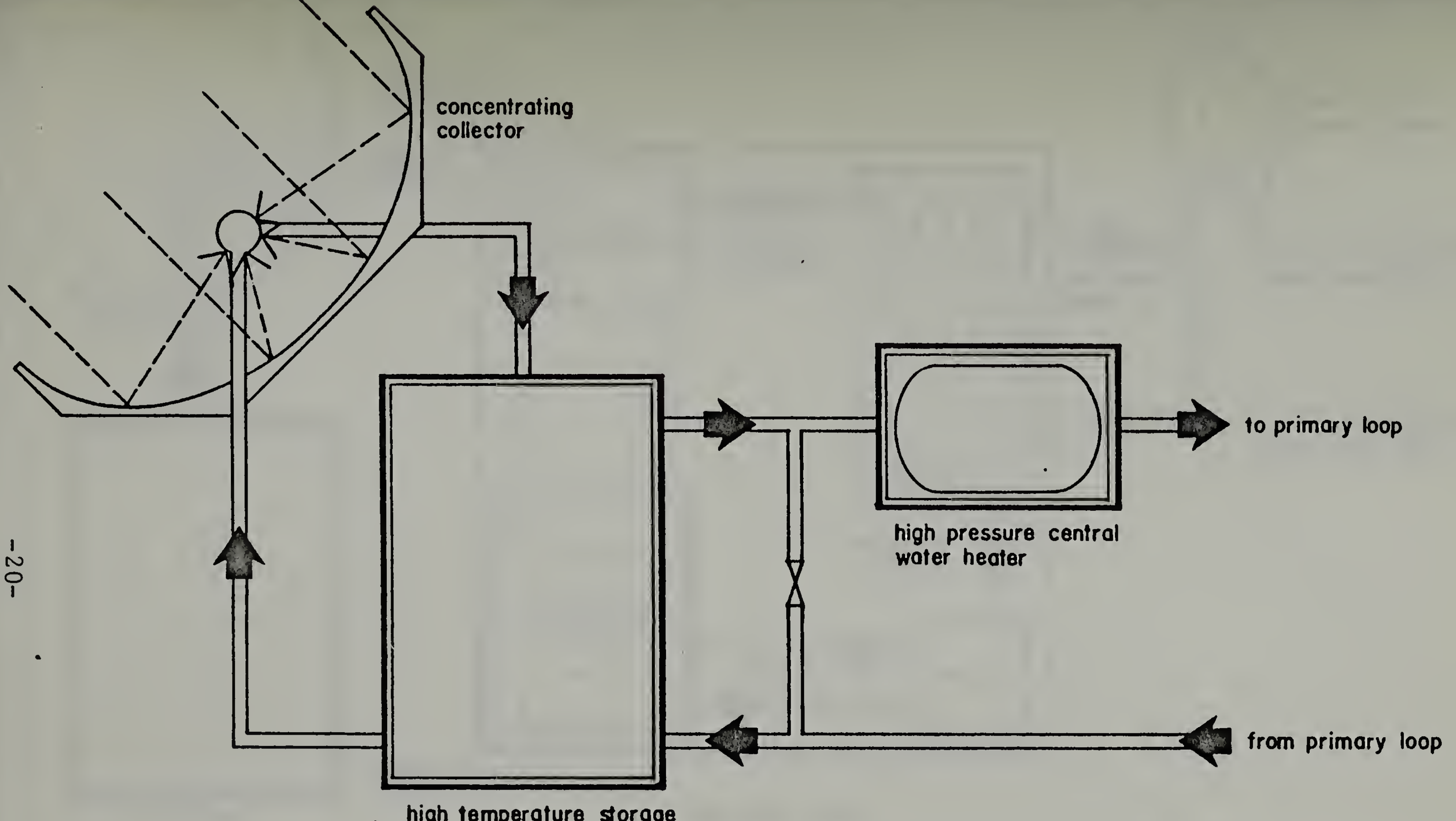


fig. 1.6.4 solar interface with central heating plant

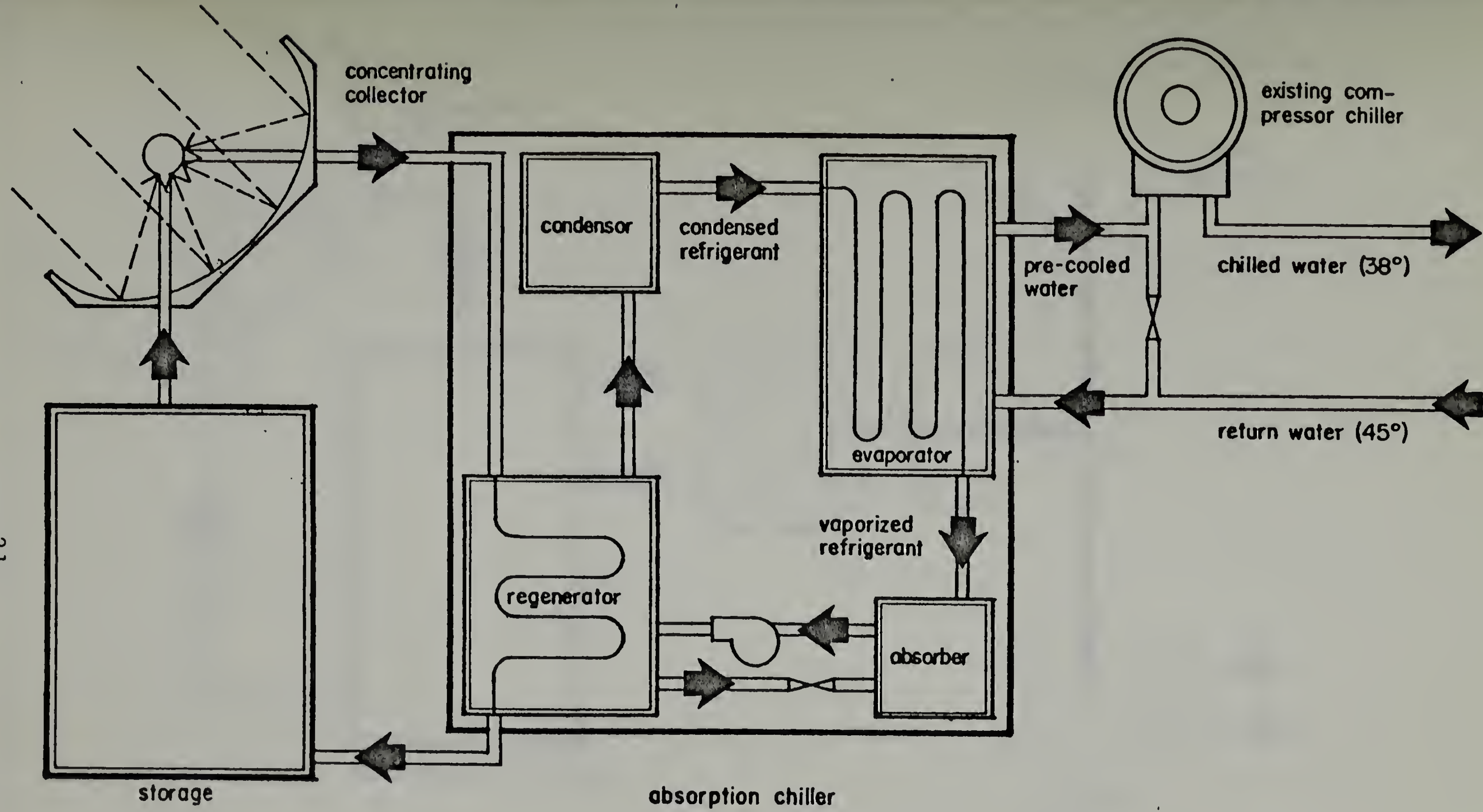


fig. 1.6.5 solar interface with compressor chiller

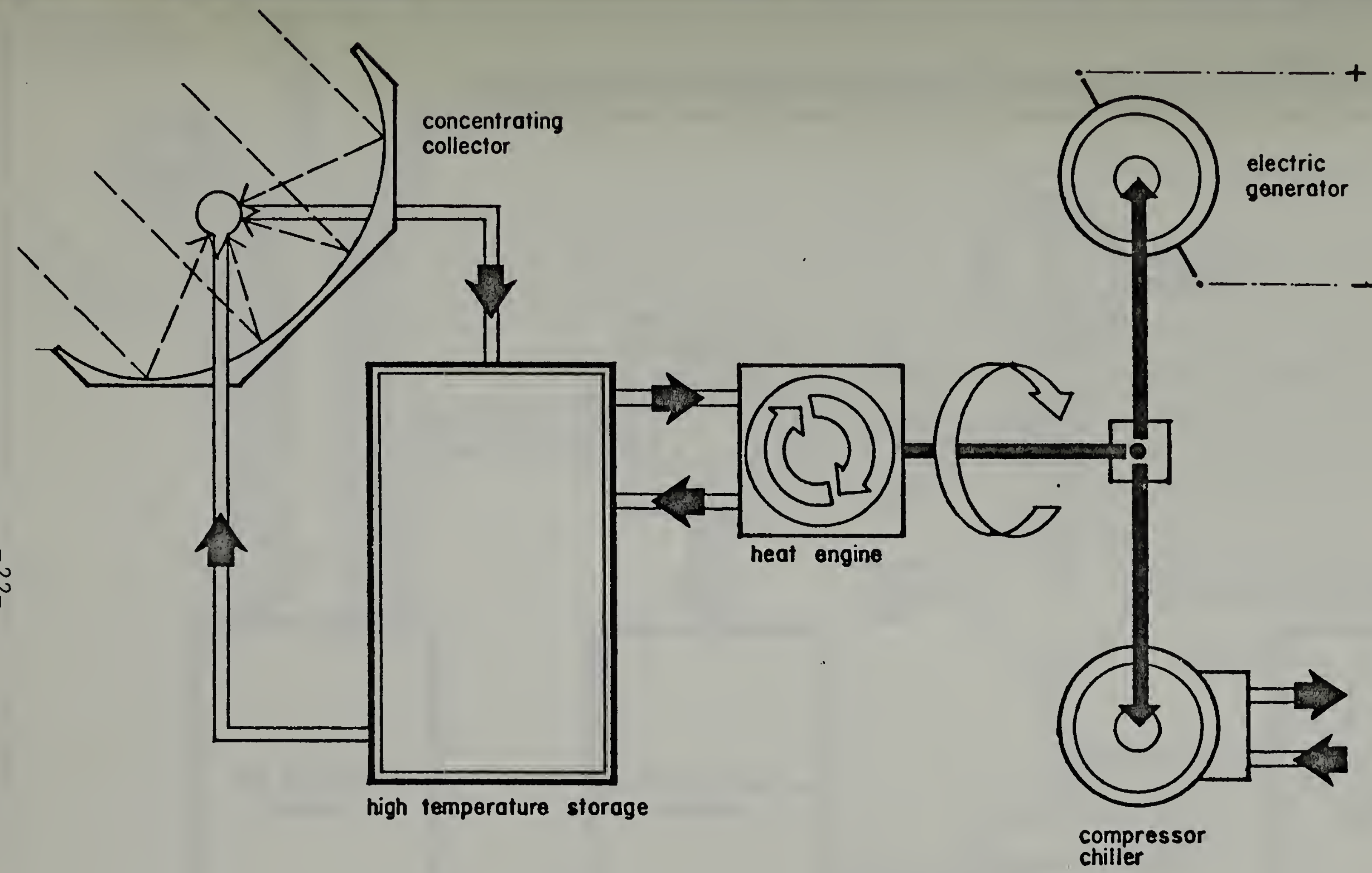


fig. 1.6.6 solar heat engine

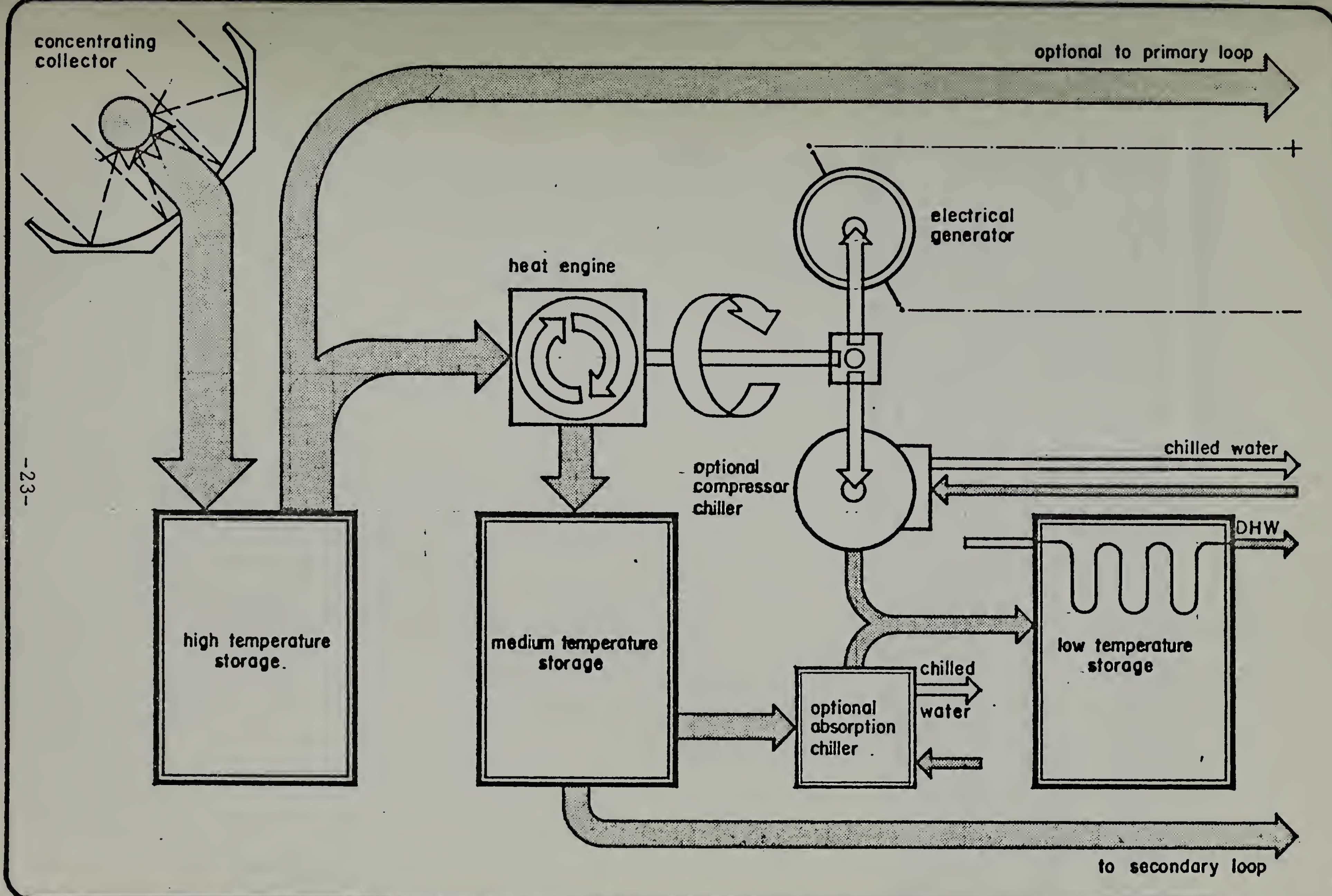


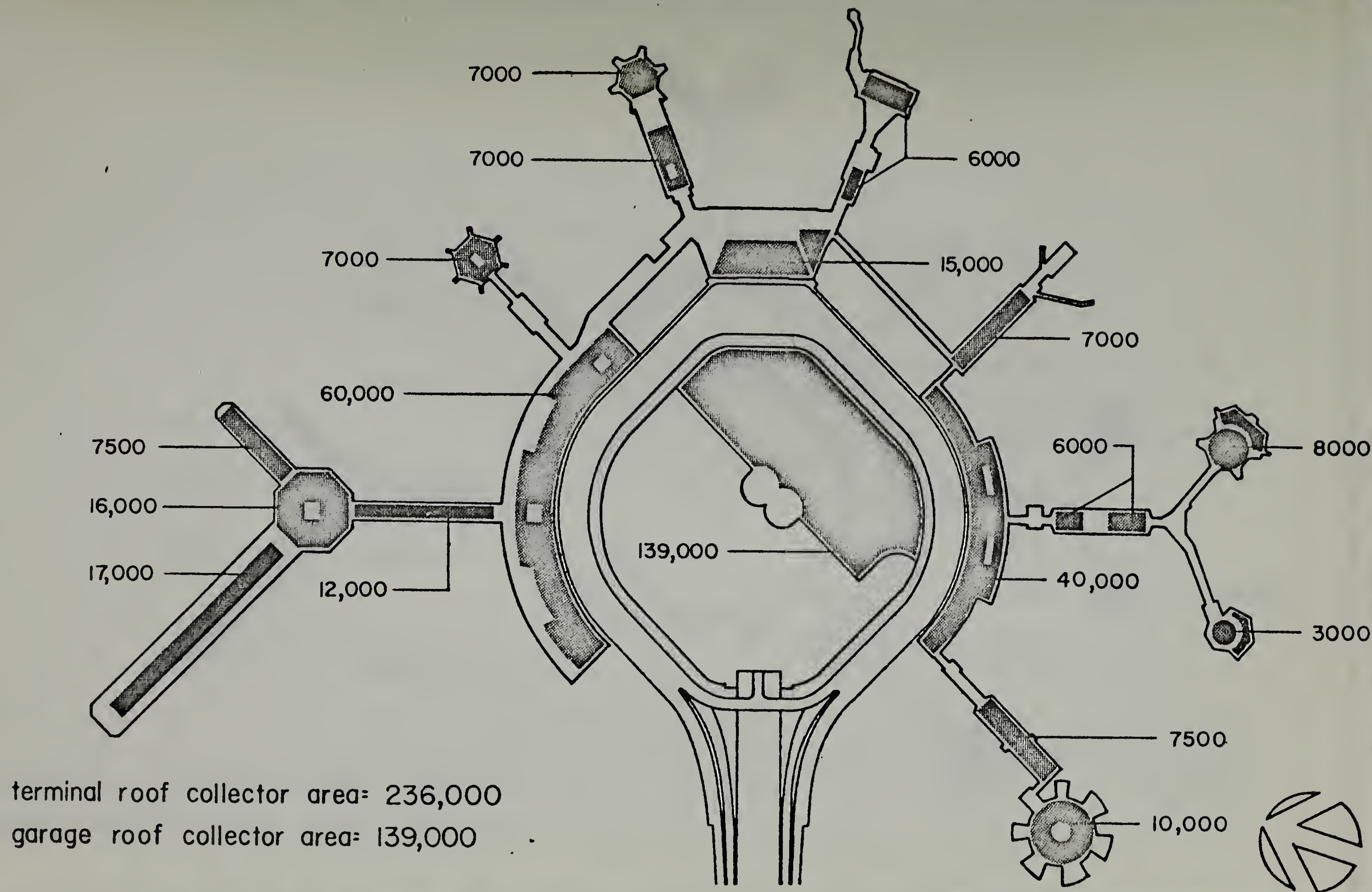
fig. 1.6.7 total energy system

1.7 Collector and Storage Locations

There is ample room to locate the optimized collector areas. A summary of optimized system sizes is given in Table 1.6.1. Potential collector locations at existing facilities are illustrated in Figure 1.7.1, with locations after the modernization and replacement phase in Figure 1.7.2.

Several options are open for storage tank locations: in mechanical rooms; above ground in the parking garage; underground in the parking garage; underground outside piers; and above ground in buildings.

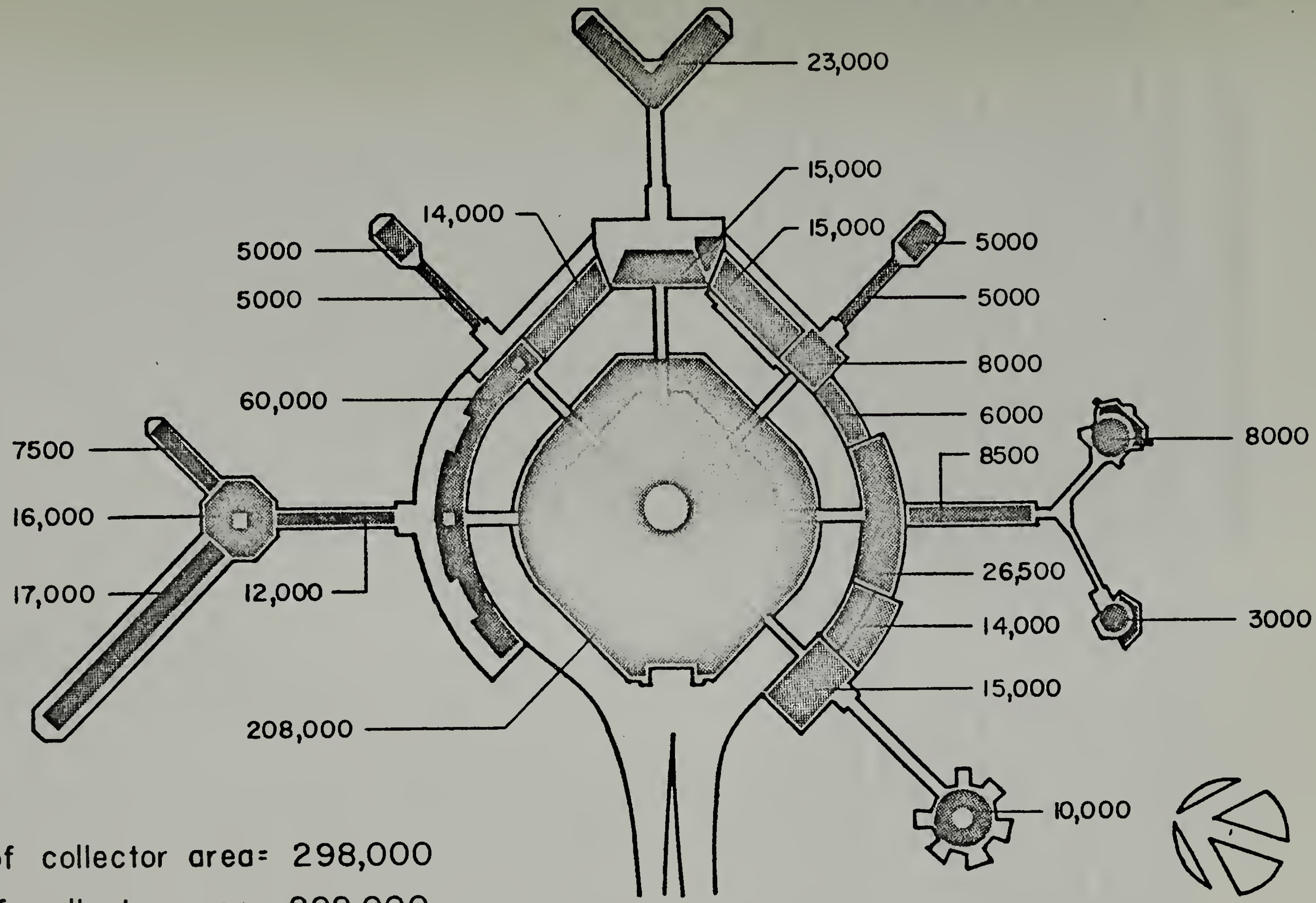
It is important that collectors and storage be located as near to each other and the load as possible. Unlike the existing heating loops, solar systems must operate on low-temperature differentials. To transfer the necessary heat requires a large volume of water. Pipe sizes will be large and significant cost savings can be realized if runs are kept to a minimum.



san francisco international airport

solar feasibility study

fig. 1.7.1 possible collector locations- with available collector area (square feet)



terminal roof collector area= 298,000

garage roof collector area= 208,000

san francisco international airport — solar feasibility study

fig. 1.7.2 possible future collector locations- with available collector area (sq. feet)

1.8 Computer Simulation and Optimization

A computer program (FCHART) was used in the study to estimate system performance and optimize system size based on life-cycle costs. The airport complex was divided into 10 zones (as shown in Table 1.6.1) for separate computer analysis. Three systems were optimized for each zone: domestic hot water heating; space heating; and a combination space and hot water heating system. A sensitivity study was made on a typical zone to determine the relative importance of different input parameters. These parameters included collector tilt; system cost; fuel price escalation; annual maintenance cost; time value of money (discount rate); and the term of the economic analysis (life cycle). The graphs of the sensitivity analyses in Section 3 of the Appendix show the relative importance of these parameters. The most significant conclusion resulting from the study was the importance of a long-lasting system that would increase the term of the economic analysis to well above 20 years in order to increase cost-effectiveness.

1.9 The Economics of Energy Conservation and Solar Energy

a. Life-cycle Cost Analysis for Direct Solar Applications. For "mechanical" solar applications, the economic analyses in this report have used "life-cycle" costs which include both initial construction costs and future operating expenditures, and have taken into consideration such factors as inflation and the opportunity cost of invested capital. Recent energy cost escalations (and shortages) have emphasized the need for life-cycle costing techniques in facility planning, and the use of this tool is now becoming accepted practice for many public agencies who must make long-term commitments for tax dollars.

The accuracy of life-cycle cost analyses is based to a major degree on assumptions about the future. These necessary assumptions include inflation and interest rates which can fluctuate greatly in response to unpredictable social or economic changes, such as a war or a depression. The price and even the availability of conventional fuels are difficult to predict for the near future, and are mere speculation in a long-term analysis.

Our life-cycle cost analyses are based on direct and precise cash-flow projections and do not reflect secondary costs or benefits which may result from effects on employment, the environment, inflation, the cost of capital, and even international relations. These secondary effects are difficult to predict but may be equally as important as the direct costs and benefits.

Due to time and budget limitations, our discussion of "passive" solar applications and energy conservation measures does not include detailed life-cycle cost analyses.

b. Economic Disadvantages of Solar Applications at the Airport. Due to the size of the project and the public nature of the owner, the San Francisco International Airport may be at an economic disadvantage when compared to other potential users of solar energy. Two of the most important factors are discussed below:

Inverse Economies of Scale. Contrary to intuition, the size of the airport and the fact that it is operated by a public agency are inimical to the objective of a highly cost-effective solar application. The ability to contract for large quantities of components and materials is an obvious positive factor, but it is far outweighed by the higher and compounded overhead and profits charged by contractors, higher labor costs, extensive insurance and bonding, and voluminous contract documents. The result is that a smaller, privately-owned

commercial enterprise might pay less per installed unit ot solar system than a large public agency. Since the airport will shortly be subject to the same utility rate schedules as private industry, it follows that what might be a cost-effective solar application in private industry will probably be less effective at the airport.

Lack of Tax Benefits. As a public agency, the airport can derive no direct benefits from existing and proposed tax incentives available to private owners for solar energy devices and conservation-related modifications. These specific energy incentives as well as traditional investment tax credits and depreciation deductions are an important factor in making solar energy attractive to the private investor.

c. Indirect Benefits and Secondary Economic Benefits. Because of the scale and visibility of the project, indirect social and secondary economic benefits which are intangible and difficult to quantify may be higher for the airport than for other potential users. Some of the factors involved are discussed below.

Fossil Fuel Conservation. Over the past three or four years, fuel shortages have already caused curtailment of industry and commerce. During this last winter factories and schools were closed down in parts of the country while businesses were limited to 40-hour weeks. It is hard for us in California to imagine gas stations and fast-food restaurants closed down at night and on weekends, but it is not difficult to imagine the devastating effect it would have on our economy. The energy-intensive industries that are hardest hit by fuel shortages generally cannot readily shift to solar utilization which is more practical for low-temperature applications. The fuels we use to warm our air to 70°F. and heat our water to 110°F. have the potential to produce the much higher temperatures required for industrial processes and our transportation needs.

Any energy saved or displaced by conservation techniques or solar utilization in buildings is freed for industrial and commercial use. The more adequate the supply of fuel to these uses, the healthier our economy will be. As fossil fuels become more scarce and a greater percentage is imported, our national and local economy will suffer. It is equally clear that the less fossil fuels we use in buildings where they are not really necessary, the more we can use them in industry where they are required.

The city does benefit directly from a healthy economy through increased tax revenues and a reduction of costs associated with unemployment, social welfare and public safety.

Increased and continued dependence on foreign fuel sources undermines a strong economy and helps create an unfavorable balance of payments. Since both the airport and City of San Francisco import fossil fuels, more capital will leave the City with little apparent corresponding increase in investment capital returning.

Local Labor. The installation of a solar system is locally labor-intensive. Most of the money spent over a period of time outside the area to buy fuels could be spent at once through the local construction industry. It is likely that a major solar installation at the airport will set an example and a trend that will stimulate the solar construction industry in this area for some time.

Inflation Hedge. Solar utilization and energy conservation are insurance against fuel inflation. The amortized cost of a solar system is high, but it is fixed. There is little disagreement that fuel costs are going to soar, and a major question is availability at any cost. Already severe shortages have demonstrated that there will be times when no fuel will be available, or comfort ranges will be forced to expand. Solar utilization and energy conservation ensure that there will be some maintenance of comfort levels. Instead of cold, for example, the "hot" water may be warm when the conventional heaters are forced to turn off.

Taxation and Public Services. Traditionally, public agencies with power of taxation, such as the City of San Francisco, have attempted to minimize the construction costs of new projects with little thought to life-cycle costs. Initial expenditures must be financed out of general tax revenues or by bonds which have to be approved by an increasingly reluctant public. With the emphasis on moderate first costs, both the public and politicians have theorized that future operating costs could be financed through guaranteed annual property tax revenues which always rise due to inflation and increased growth.

The exponentially increasing annual cost of public employee pensions in such cities as New York was one of the first indications that commitments for future tax revenues had outstripped the taxable resources. It should be noted that only the federal

government can print additional money to finance budget deficits. Now local governmental agencies are just beginning to feel the effects of double-digit energy inflation which has no apparent end. For the first time in history, many cities are now considering or implementing significant cuts in energy-related public services such as street lighting. Life-cycle costing techniques are now being increasingly utilized at many levels of government to analyze the microeconomic relationship of initial and long-term costs of various projects and programs. Energy conservation typically is an area that may involve increased first costs to achieve lower life-cycle costs.

Indications are that energy conservation in building is an economically viable alternative, and will become increasingly so as energy costs rise. In terms of an energy economy, it has been estimated, for example, that every BTU required in the construction of a building is matched by another BTU during each year of its life. Thus, in terms of energy conservation, front-end investments get returns of 30, 40, 50 or even 100 to one. Of course, this analysis does not necessarily translate into similar economic payoffs. It does, however, suggest the possibilities that could be tapped if the economic consideration of alternative building construction included energy conservation versus non-energy conservation techniques.

Macroeconomic Impacts. A variety of studies and estimates suggests that we are entering a period in which there will be increasing competition for scarce capital. Thus it cannot be safely assumed that all energy-generating demands can be met, because they may encounter a capital shortage that cannot necessarily be overcome by increasing the interest rates. The problem goes beyond national boundaries. Capital currently returns interest rates of 14 per cent or more in some countries. The rapidly growing international capital market, supplemented by the emerging network of multinational corporations, makes possible an economic decision-making structure unlike those which have traditionally prevailed.

The inflationary price implications of scarce critical materials are already evident even in the present stage of the energy problem. Capital for energy-efficient buildings could be a wise macroeconomic strategy. One key study (American Institute of Architects, Energy and the Built Environment: A Gap in Current Strategies) predicts that

the sources of future investment capital will be heavily affected by increasing energy costs resulting in a severe capital shortage within the next 20 years. One solution to the projected shortage is to convert consumption expenditures to capital investments, an alternative that must be implemented now to be effective later. The study concludes that the energy conservation strategy is economically self-sustaining at a better rate of return than is generally expected from long-term investments in construction and in operation of utility-operated conventional energy systems.

The commitment to future fossil fuel consumption will result in a diminishing return on our invested capital. Barry Commoner, in The Poverty of Power, illustrates this point:

> As petroleum reserves are consumed, the amount of capital needed to support deeper drilling and more elaborate extraction processes rises sharply, so that the amount of oil produced per dollar of invested capital (the productivity of capital) falls.

This has made itself painfully clear as the oil companies lobby for larger profits to acquire more capital. Barry Commoner goes on to say:

> Meanwhile, we are failing to draw upon the one source of energy which is renewable; is not subject to diminishing returns; it is technologically simple; is compatible with the environment; and is economically capable of counteracting the inflationary effect of conventional energy production—the sun. Unlike present energy sources, solar energy is wholly unaffected by the law of diminishing returns. The future availability of solar energy is not reduced by its present use, for the ultimate source—the huge nuclear reaction deep in the sun's interior—will continue to send enormous amounts of energy toward the earth regardless of what its inhabitants choose to do with it....
>
> Unlike conventional energy production, the use of solar energy does not automatically increase its future costs and the demand for capital. Solar energy can therefore be produced without imposing

on the economy the inflationary effects of rising energy prices and rates of interest. Indeed, an investment of capital in solar energy now is a hedge against future inflation, for it eliminates the need to buy fuel at a constantly inflating price. By reducing the demand for conventional fuels, solar energy, developed on a sufficiently large scale, could in fact even reduce the price of conventional energy and soften its inflationary impact. Solar energy is more than a superior economic alternative to conventional energy sources; it is also an antidote to their catastrophic economic effects.

Social Stability. A very recent staff report from the Congressional Office of Technology Assessment for the House ad hoc energy committee found that energy experts, far from doubting the reality of the energy crisis, consider the situation even more serious than recent private reports have suggested. The report quoted the director of the performing agency:

> The consensus is that the problem is so grave, it contains the seeds of depression, revolution, and even world war.

The concern is that the world demand for oil will continue to grow and that producing nations will restrict supply, causing sharp price increases and increased tensions both at home and abroad.

Image and Civic Pride. Many of the existing or proposed physical improvements at the airport and other public facilities are difficult to justify on a strict cash-flow accounting and rate of return basis. There is no question that construction of the new piers costs more than the existing piers. The handsome facades were judged on some basis other than economics. A good image that promotes civic pride is extremely valuable but difficult to quantify. Likewise, environmental improvements such as solar applications and increased energy efficiency have a value beyond direct economic accounting.

Why Not Wait for the Cost to Go Down? A misconception exists that the cost of solar utilization will come down in price. This may be true for some of the more exotic applications such as electrical production, but it is extremely unlikely in the highly developed technologies for water and space heating. Most of the costs associated with these systems are for conventional materials and labor. Even the specialized components such as collectors and controls are mass-produced and unlikely to drop in price. The cost of an installed solar system will undoubtedly rise with the general increases in the construction industry.

1.10 Sources of Funding

At the present time, the most promising source of external funding is the federal solar demonstration program. Under this program the Department of Housing and Urban Development (HUD) carries out the residential demonstrations while the Energy Research and Development Administration (ERDA) handles the commercial demonstrations. In addition, the Department of Defense and the General Services Administration direct federal building demonstration programs.

The airport would qualify under ERDA's program, through which up to 100 per cent of a solar system's cost will be funded. Second cycle winners (five cycles are planned) were announced in May of 1977. A solicitation for the third cycle should be issued soon with proposals due by the end of 1977. Although only about 10 per cent of the proposals have been funded in the past, a well written proposal from the airport would be well received. Interactive Resources, Inc., for example, has had 100 per cent success in writing proposals under the commercial demonstration program. The airport's high degree of visability would certainly augment the demonstration nature and acceptability of this project under this program.

Special ERDA solicitations have been issued for hospitals, hotels and motels. The Carter administration has proposed funds to solarize schools, hospitals and federal buildings. Several bills in Congress also propose solar funds for federal buildings. However, no program to date includes provisions specifically for local government participation. Likewise, the state government through the Energy Commission and the State Architect has initiated programs to apply solar technologies to state-owned buildings, but has no programs or formal plans for local entities.

A copy of the ERDA solicitations can be obtained by requesting a PON (Program Opportunity Notice) for the next cycle of commercial solar demonstrations and other applicable special solicitations, from

San Francisco Operations Office
Energy Research and Development Administration
1333 Broadway
Oakland, CA 94612, or

Energy Research and Development Administration
Washington, DC

1.11 Special Requirements of the Federal Aviation Administration

a. Visual Glare. There is a potential glare problem with covering the terminal and pier roofs at the airport with solar collectors. The air traffic controllers situated in the new control tower could be subjected to heavy eye strain and possible disabling glare reflecting off the glass covered solar collectors.

A study of the direction of reflections off a collector tilted 40° up from the horizontal was done. The minimum altitude angle of the reflection happens in June at 12 noon. This angle is 25° above horizontal. Next investigated was the geometric relationship between the terminal and pier roofs and the control tower. The largest angle off the horizontal of any direct line from a potential collector site to the control tower is 13°. This occurs between the front edge of the North Terminal roof and the control tower. Since the reflection altitude angle never goes below 25°, the air traffic controllers will not see any reflection. However, collectors placed on a structure over the parking garage north of an east-west axis drawn through the control tower could cause reflections into the control tower unless they are screened out by the control tower itself.

To further ensure that the glare from solar collectors will not create problems at the airport, we recommend the use of specially-treated, non-reflective glazing. This is often accomplished by texturing glass to diffuse the reflected glare.

The FAA will want to judge on this matter before a solar system is installed.

b. Radar Interference. The Instrument Landing Systems are located at the end of the runways. Any large metal construction near the runway could interfere with its operation. Installing copper or aluminum collectors on the terminal and pier roofs could therefore cause interference.

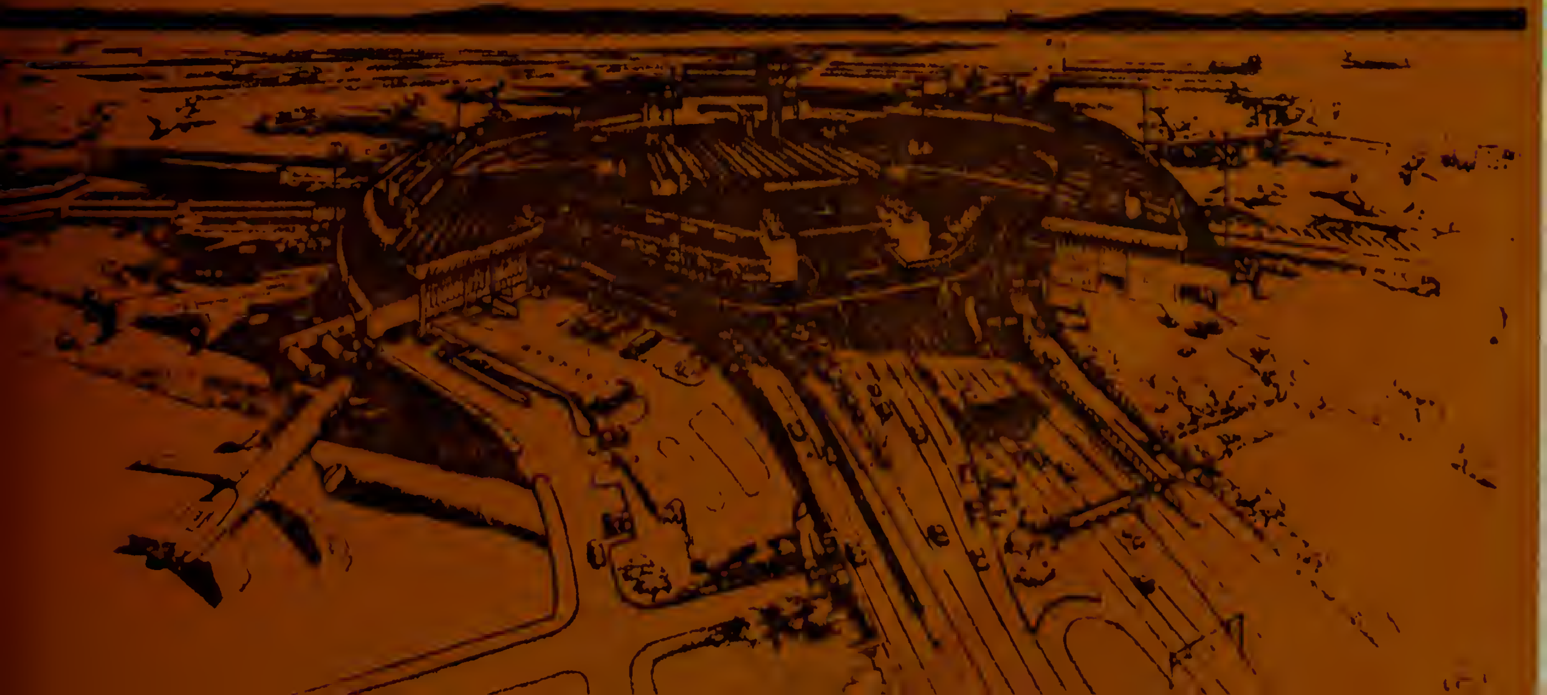
The FAA will want to judge on this matter also before a solar system is installed.

solar energy feasibility study
at the
san francisco international airport

appendix I: sections 2-5

prepared for
the airports commission
of
the city & county of san francisco
california

by
interactive resources, inc.
with
gayner engineers
ayres associates



Solar Energy Feasibility Study

at the

San Francisco International Airport

Prepared for

The Airports Commission of
The City and County of San Francisco
California

by

Interactive Resources, Inc.
Point Richmond, California

with

Gayner Engineers
San Francisco, California

and

Ayres Associates
Los Angeles, California

September 1977

Appendix I: Table of Contents

SECTION 2

EXISTING CONDITIONS AND

ENERGY USAGE CALCULATIONS

2. Existing Conditions and Energy Usage Calculations

2.1 Site Conditions

Present airport passenger facilities consist of the Central and South Terminals with their respective piers and boarding areas (see Figure 2.1.1). A new North Terminal and Piers H and I are under construction and scheduled for completion in mid-1978. Construction has also begun on expanding the garage.

Expansion of the airport is expected to continue with the modernization and replacement phase as shown in Figure 2.1.2. This work includes:

Stage 1: South Terminal West Addition
Boarding Area G and Connector

Stage 2: Central Terminal Modifications
New Piers E and F

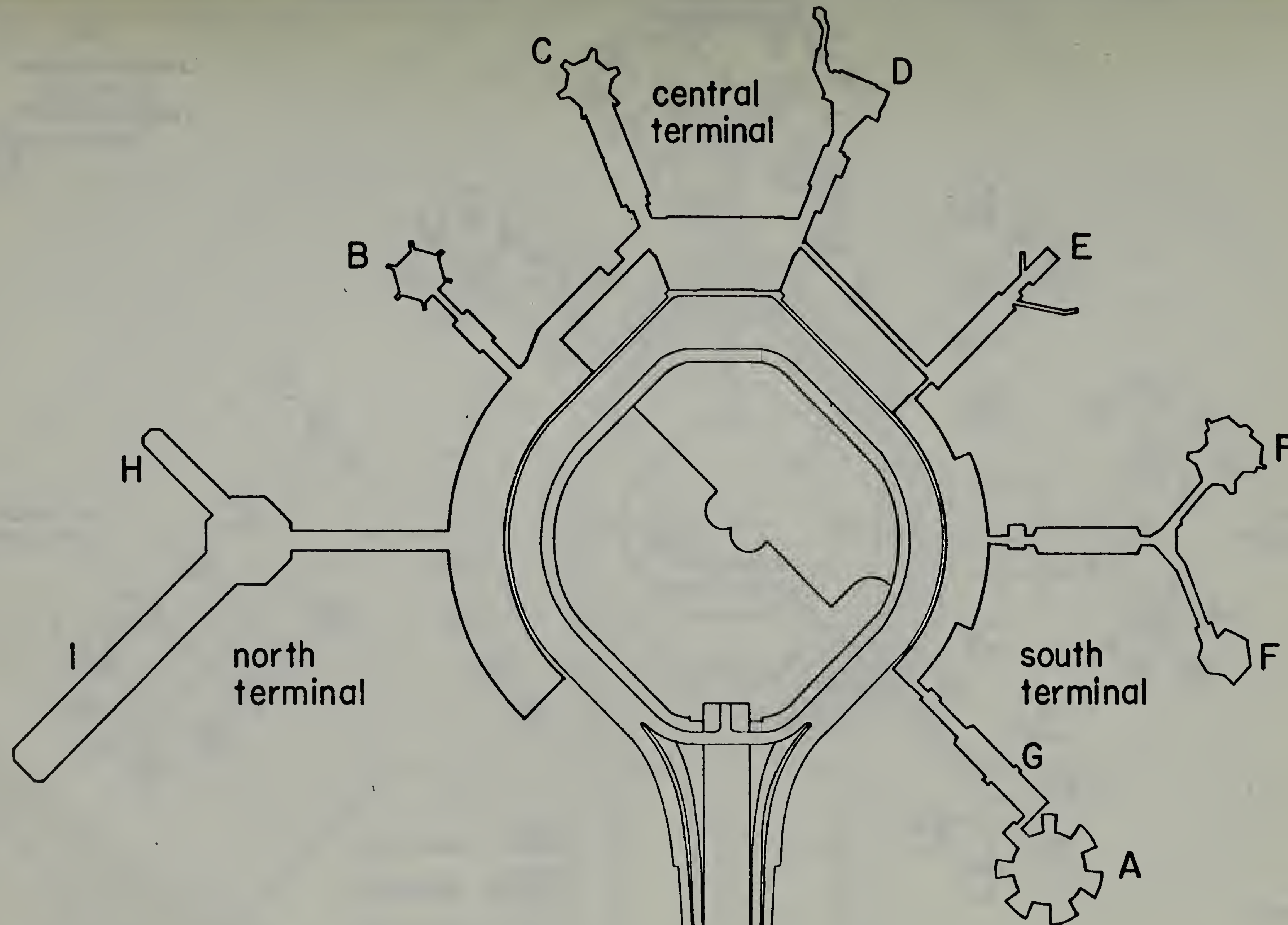
Stage 3: South Terminal Modifications
New Pier D
Renovation of Piers B and C.

2.2 Future Central Plant

A new central plant designed in Contract 1000, Garage Stage IV, Superstructure Addition, is presently under construction. This central plant is located in the ground level of the new garage in Segment 2 (diametrically opposite the Central Terminal).

Initially the central plant will have two 3,000-ton electrically-driven centrifugal chillers and three 25-million-BTUH-output, high-temperature hot water boilers. The ultimate capacity of the central plant will be 13,500 tons of cooling and 100 million BTUH of heating.

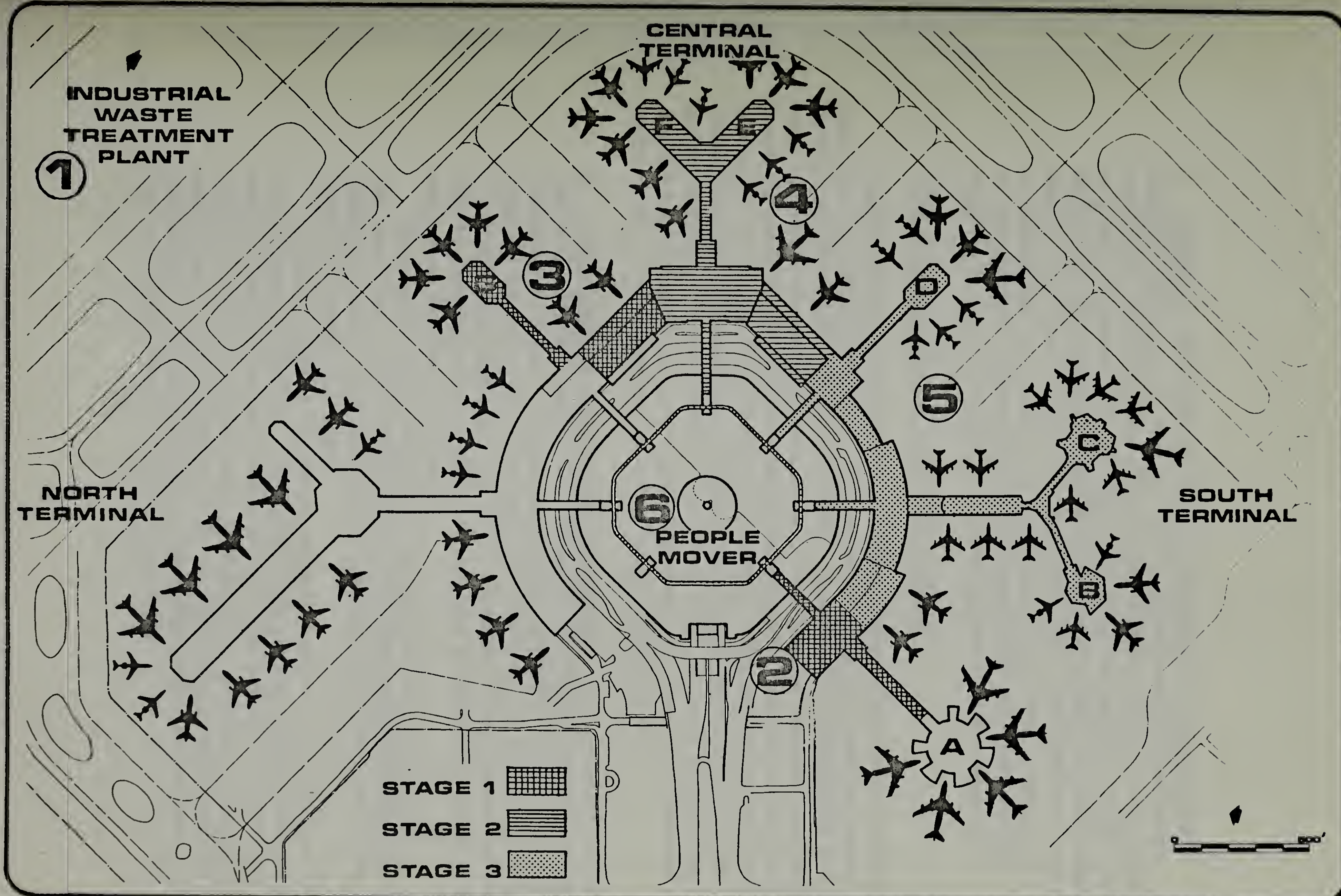
a. Cooling. The chilled water is circulated through a primary loop which varies from 38°F. supply water temperature to 60°F. return water temperature. Secondary pumps at the various terminal mechanical rooms provide secondary loop chilled water to cooling coils at 44°F. supply and 60°F. return water temperature. The primary chilled water runs in a loop around the perimeter of the entire garage.



san francisco international airport

solar feasibility study

fig. 2.1.1 existing site plan



san francisco international airport

solar feasibility study

fig. 2.1.2 modernization & replacement phase- definitive plan

b. Heating. The high temperature heating hot water (HTHW) system is designed to furnish $400^{\circ}F$. primary supply hot water and $250^{\circ}F$. return water. The primary HTHW system is distributed in a loop adjacent to the primary chilled water piping. Water-to-water heat exchangers at various mechanical rooms provide secondary heating hot water at $200^{\circ}F$. to heating coils. The boilers are fired by natural gas and convert to No. 2 diesel oil when natural gas is unavailable. Present fuel oil storage is 80,000 gallons with provisions to add additional 80,000-gallons storage capacity.

2.3 Method of Calculating Energy Consumption

The heating and cooling annual energy consumption for the various terminals was estimated by the "Equivalent Full Load Operating Hours" method published by P G and E in 1967. This method provides for a first step estimation by manual calculation. The designed heating and cooling loads for each of the terminal areas were obtained from the design documents of SFIA Contract 1000, Garage Stage IV, Superstructure Addition. These are the projected future heating and cooling loads for the future South Terminal, Central Terminal and Piers B, C, D, E, F and FF, but are the actual design heating and cooling loads for the North Terminal, Piers H and I and connector presently under construction.

a. Space Heating and Cooling Calculations. The heating energy calculated by this method for the South and Central Terminals was compared with the available utility bills for 1975-76. The calculated estimate was found to be within five per cent of the actual usage at an equilibrium temperature of $55^{\circ}F$. ambient. (Equilibrium temperature is defined as the outside temperature at which the building would require no heating or cooling.)

Generally, engineering calculations are made to determine the worst cases under which the mechanical equipment will operate. Therefore, the design heat loss or gain has little relationship to the actual energy consumed.

A solar utilizing system is generally sized in accordance with the average conditions. Therefore, an optimally-sized solar system will not satisfy the load during the extreme periods. In order to optimize the size of the solar system and to estimate its performance and value, a close estimate of the actual energy requirement is necessary. Computer modeling can provide the best estimate if realistic utility histories are not available.

Modeling will not only help in ascertaining the feasibility of solar utilization, but will closely estimate the energy savings of various conservation options that may prove more cost-effective than solar utilization. Energy conservation and solar options must be considered simultaneously as implementation of conservation measures will lower the energy load and reduce the optimum solar system size.

In this study we used the original calculations developed for sizing the airport's central plant; therefore, our optimum solar system is likely oversized. Undoubtedly, the energy loads of the South and Central Terminals will be lower than originally anticipated (energy conservation has a high priority in the revised plan) and additional modifications to the North Terminal may further reduce the total energy load.

Computer modeling and energy system optimization should be incorporated in the design phase of all future airport construction including remodeling of the Central and South Terminals and boarding areas. Modeling of existing buildings including the North Terminal and Piers H and I will help in the sizing of solar equipment and in assessing the impact and cost-effectiveness of alternate conservation strategies.

c. Domestic Hot Water Heating Calculations. Domestic hot water consumption was estimated by a fixture count method. A figure of 1.5 GPM per lavatory and 2.25 GPM per service sink were used to estimate the average daily hot water consumption based on a two-hour peak load period. Since the domestic hot water heaters were not separately metered, it was not possible to check the calculated usage figures.

d. Sub-metering. The most appropriate mechanical solar load is domestic hot water; however, the figures we used to estimate the load and optimize the system's size were based on the number of fixtures and an assumed use per fixture. This method is crude and quite possibly inaccurate.

The best method of accurately determining the load is to install water flow meters on the supply line to each water heater. The importance of an accurate load estimate cannot be understated. Conventional engineering calls for the oversizing or safe sizing of mechanical equipment. Oversizing of solar equipment is costly. Sub-metering will provide us with exact loads for each heater location. Solar collector and storage systems can then be specifically designed (optimized) for each water heating zone.

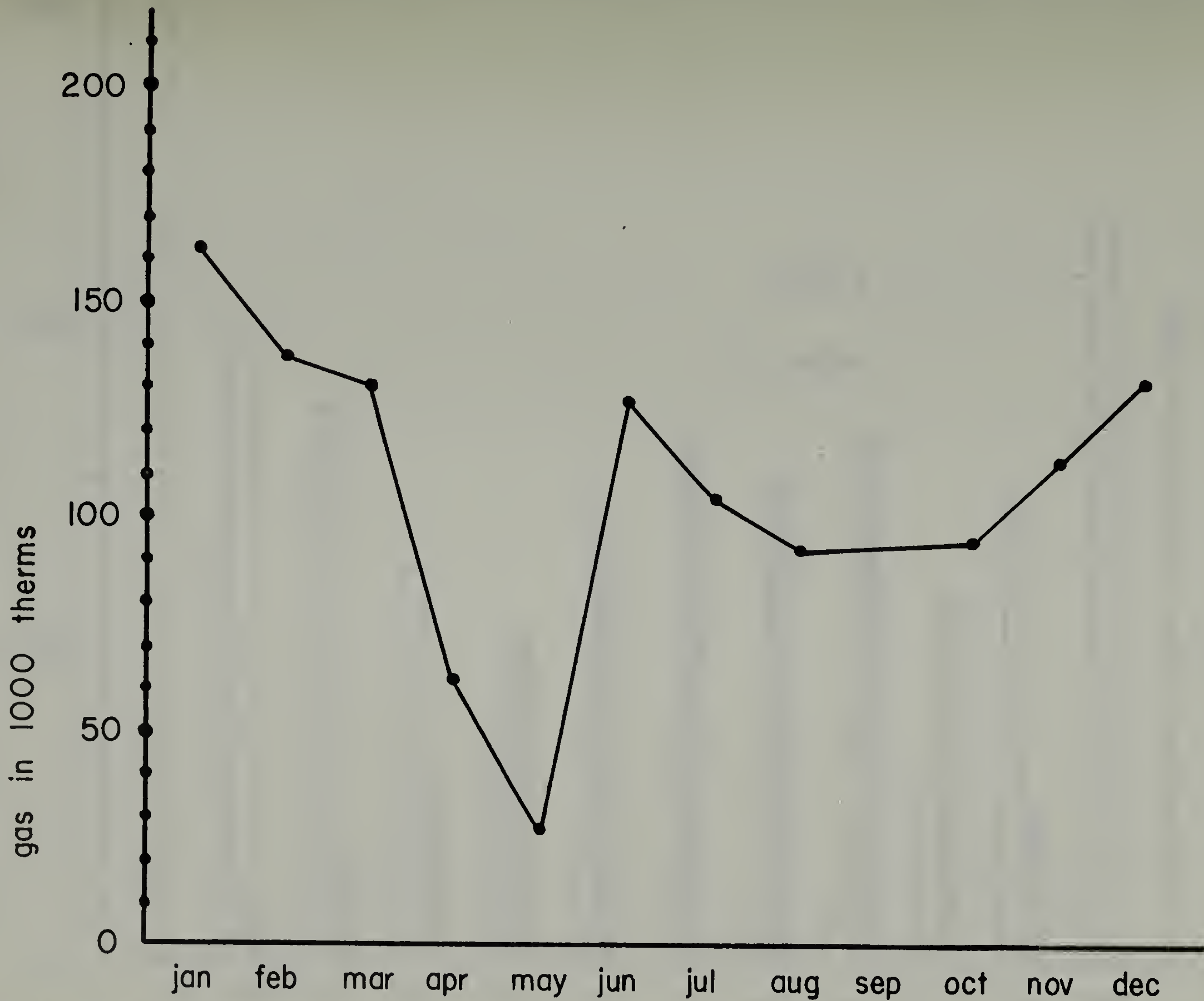
Sub-metering of the space heating system would not reflect potential conservation steps, but it would provide a check of the base used in the computer simulation and analysis (as recommended).

Although with sub-metering and computer simulation the energy load estimates may change and the optimum solar system size and cost will adjust, the relative economics and cost-effectiveness will remain constant. A smaller system will supply a smaller than originally estimated load or a larger system will supply a larger load. The unit cost and effectiveness will remain fairly equal.

Table 2.3.1

Estimated Energy Use
San Francisco International Airport

	Domestic Hot Water Heating (therms/year)	Space Heating (therms/year)	Domestic Hot Water and Space Heating (therms/year)
South Terminal	13,100	177,800	190,900
Central Terminal	24,000	98,900	122,900
North Terminal	14,100	244,600	258,700
Piers H and I	19,800	126,800	146,500
Pier B	4,600	38,500	43,100
Pier C	8,800	38,500	47,300
Pier D	5,400	38,400	43,800
Pier E	8,000	36,700	44,700
Pier F	4,900	152,200	157,100
Rotunda A	3,300	99,700	103,000
Total Airport	160,000	1,052,100	1,212,100

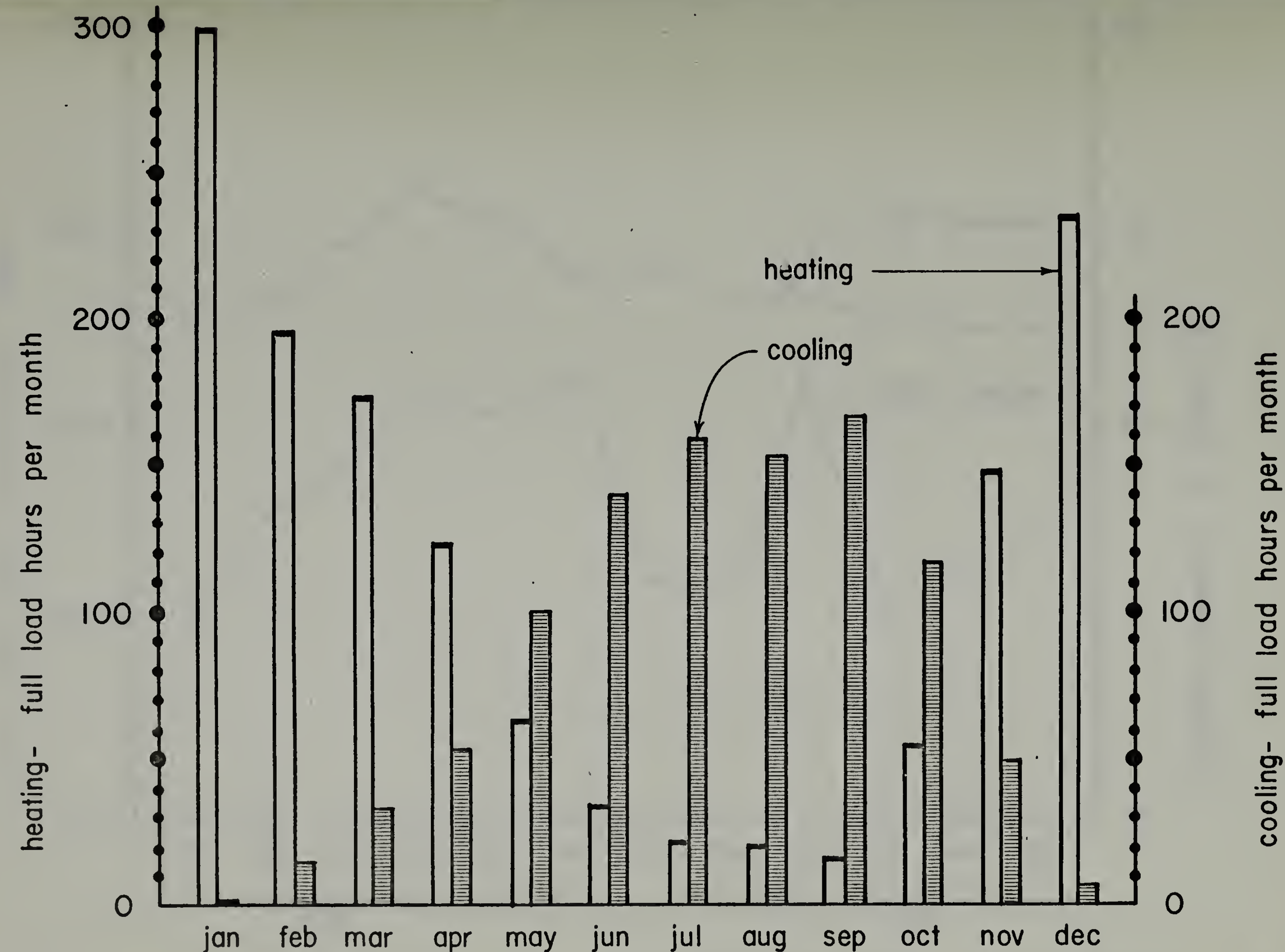


san francisco international airport

solar feasibility study

fig. 2.3.1

1976 gas usage

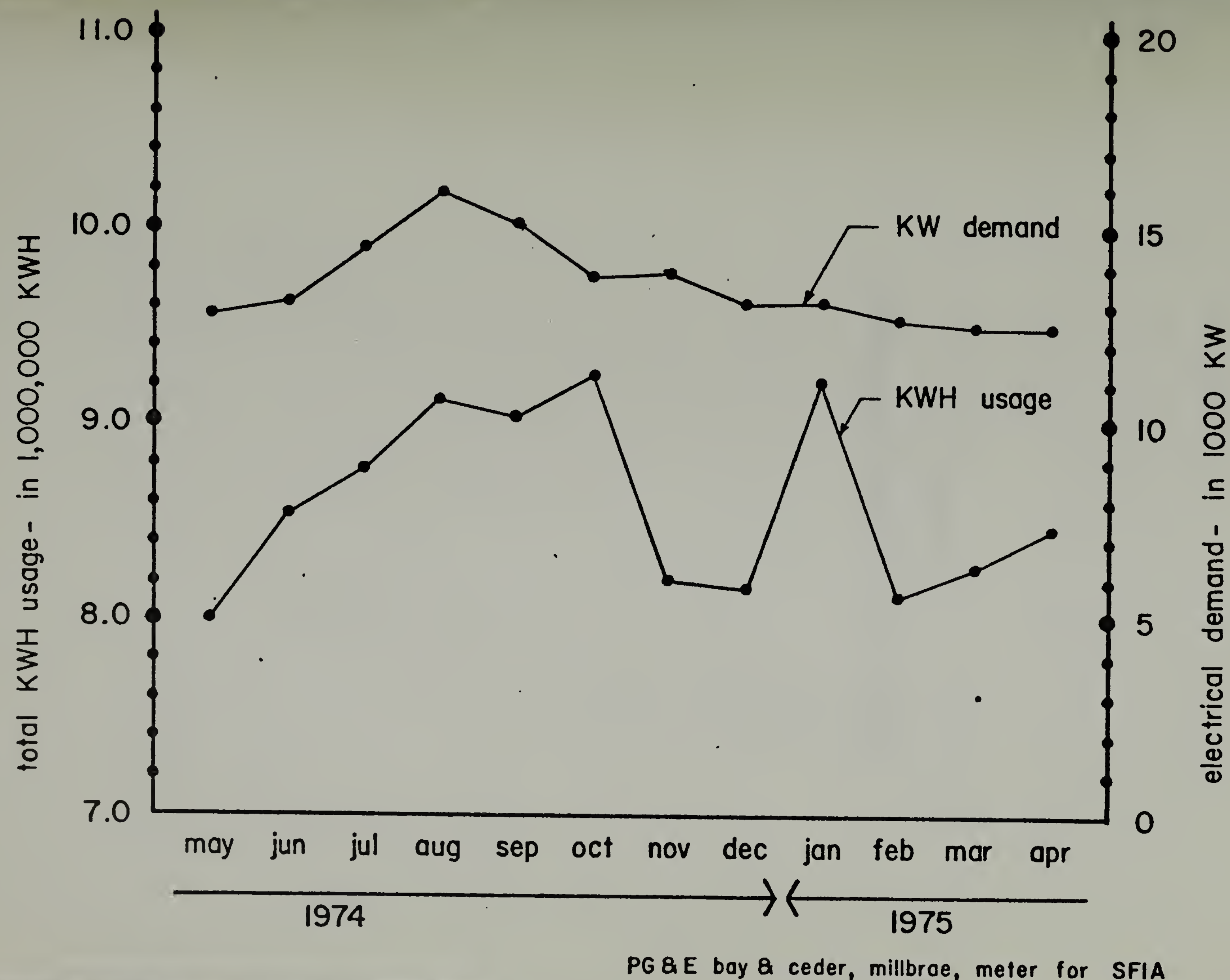


san francisco international airport

solar feasibility study

fig. 2.3.2

full load heating & cooling hours- at 55°F equilibrium temperature

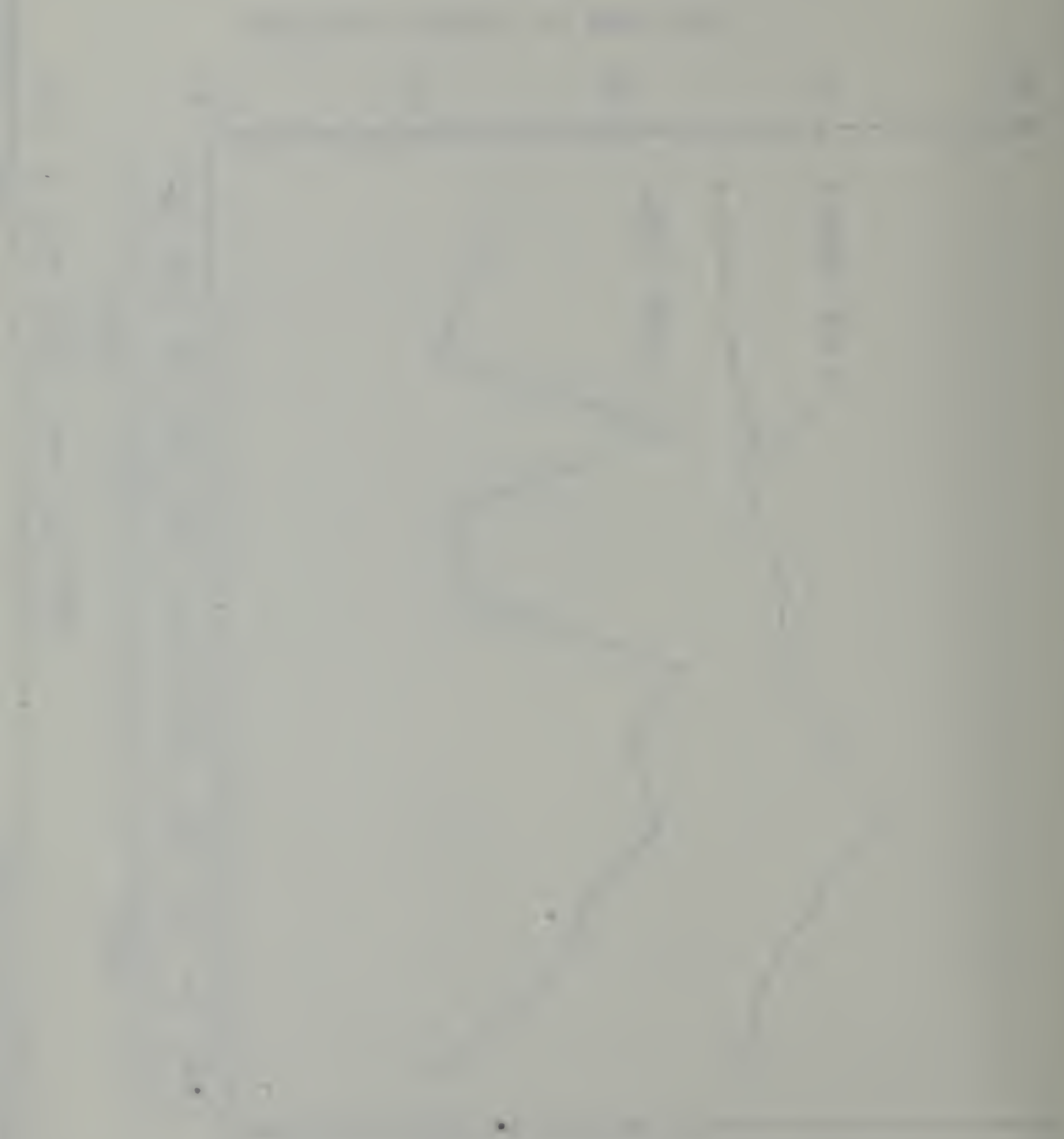


san francisco international airport

solar feasibility study

fig. 5.2.1

annual electrical demand and usage



SECTION 3

ACTIVE SOLAR ENERGY APPLICATIONS

3. Active Solar Energy Applications

3.1 Available Components

There are literally hundreds of solar equipment manufacturers offering a wide variety of solar products. There are almost endless combinations of materials, sizes, shapes and manufacturing techniques. There is no one combination of equipment which will stand out as an obvious best choice. The options, however, can be significantly narrowed by a simple product-to-function analysis.

a. Flat Plate Collectors. The most common collectors on the market today are flat plate collectors. They consist of a black plate which converts sunlight into heat, then transfers that heat to a fluid, usually water or air, which is passed over, under, around or through the plate. These collectors are most applicable and cost-effective for producing low and medium temperatures—under 100^{o}F. unglazed, under 200^{o}F. glazed.

Liquid absorber plates. Copper plates offer excellent heat transfer properties and are corrosion resistant. They are compatible with potable water enabling them to be used in the direct heating of domestic hot water. Copper is the best choice for any system using water as the transfer fluid. It costs more than the other metals, but cost comparisons should be made on whole systems where trade-offs occur from the use of different collectors.

Aluminum also offers excellent heat transfer properties, but is highly corrosive. It can only be used in conjunction with a non-corrosive transfer fluid, which also means the use of an exchanger to transfer heat to storage and a corresponding loss in system efficiency.

Aluminum plates with copper flow tubes offer a cost versus corrosion compromise. The major element is aluminum, but water only flows through copper, eliminating the corrosive problems of all-aluminum plates. In these plates the bond between the copper tube and the aluminum plate is critical to collector performance.

Steel plates have one-tenth the thermal conductivity of aluminum and one-twentieth that of copper. They may be used cautiously with water, but are more reliable with a non-corrosive transfer fluid.

Two types of liquid absorber plates can be seriously considered for use at the airport: (1.) Tube and plate, in which fluid passes through tubes which are attached to or are part of the absorber plate; and (2.) Envelope, in which fluid passes between two plates which are fastened around the edges and intermittently fastened throughout.

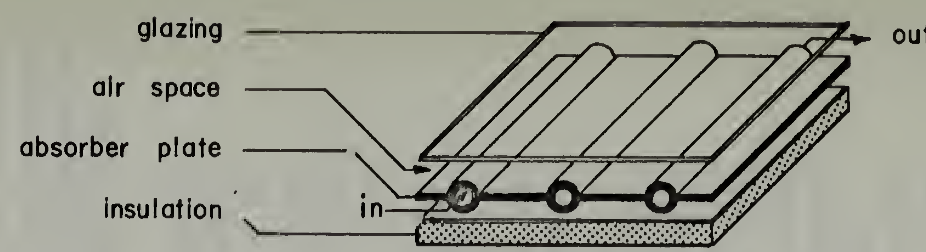
Because envelope absorbers require more materials and greater structural strength, most manufacturers build tube and plate absorbers instead. Tube and plate absorbers can take higher pressures and offer the best resistance to scaling, but are not quite as efficient.

Air Absorber Plates. In principle, an air absorber plate works the same as a liquid one, but uses air as the transfer fluid. The best products are designed with airflow behind the plate or through channels so the air will not come in contact with the glazing which would increase convective losses. Air absorber plates do not have the corrosion or freezing problems of liquid plates.

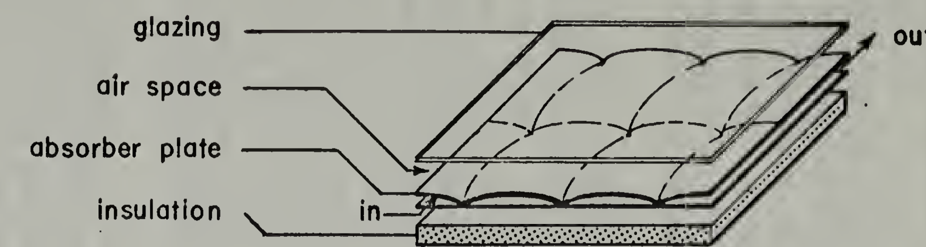
Coatings. A number of satisfactory black coatings are available for absorber plates. Black surfaces, of course, absorb more light than other colors, but also re-radiate more heat. To counteract this, special coatings known as selective surfaces, have been and continue to be developed. When applied to an absorber plate, they increase the amount of sunlight absorbed, but at the same time emit only small amounts of heat. This results in higher efficiencies. The degree to which they accomplish this varies from product to product. Some selective surfaces are expensive, delicate and their dependability questionable.

Glazing. Glazing allows higher collector temperatures in the absorber by insulating it from the outside air while still permitting sunlight to pass through. Collector glazing is usually made of glass or a transparent plastic. Glass is more durable than plastic, but is subject to breakage. Plastics are subject to ultraviolet degradation. Glass is also more expensive and has better optical properties.

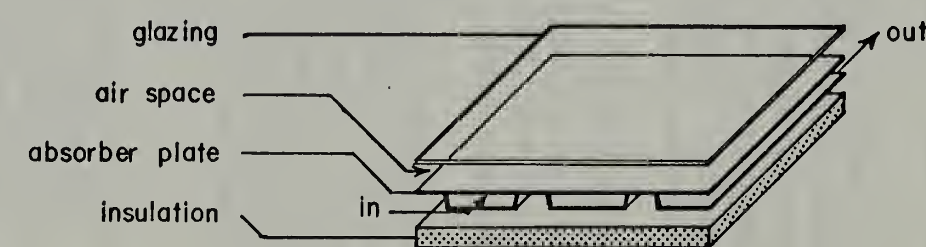
For San Francisco, one cover plate is adequate for domestic hot water and space heating applications. Double glazing would be necessary for high temperature applications such as air conditioning.



tube and plate collector (liquid transfer medium)



envelope collector (liquid transfer medium)



air collector (air transfer medium)

fig. 3.1.1 collector types

Insulation. Insulation is placed behind and to the sides of the absorber plate to reduce heat losses. Besides good thermal performance, it should be able to withstand the high stagnation temperatures (around 300°F.) which will sometimes occur.

Prefabricated versus Site-fabricated. Collectors can be bought and assembled two ways. One way is to buy collectors which have absorber plate, glazing and insulation pre-assembled into a metal frame. These collectors are typically available in sizes around four-feet-by-eight-feet. Prefabricated collectors must still be installed on the site and manifolded together.

Another option is to buy components separately and assemble them on the site. Whole collector arrays can be constructed as one unit. Insulation is laid on a support deck, and the absorber plates over that. The plates are manifolded together and the entire area is glazed.

Maintenance costs on the prefabricated collectors are lower because their modular construction makes them easy to replace. Both types will perform equally well. The major difference is cost.Trade-offs can occur between the price of factory assembling and on-site, labor-intensive construction. The advantages will vary from case to case, but cost savings are possible in site-fabricated collectors.

b. High-temperature Collectors. Some applications such as air conditioning and electrical generation require higher temperatures than are feasible with typical flat plate collectors. There are two approaches to achieving higher temperatures:

Evacuated tubes are collectors which utilize a partial vacuum between the absorber and single glazing or between double glazing to significantly reduce heat losses.

Focusing collectors are required when very high temperatures are necessary. They use lenses or reflective surfaces to focus sunlight on to a small absorber. Most of these must track the sun through the sky and therefore require tracking mechanisms. Other less efficient and less expensive collectors focus sunlight, but do not track the sun.

Manufacturers are promising tracking collectors with high efficiencies at costs only slightly higher than flat-plate collectors. These utilize a relatively simple, but accurate, tracking logic system. Most of the economically attractive focusing collectors are still in the development or early commercialization stages. Therefore, there is little or no track record on the

possible problems related to their durability and maintenance. A normal accumulation of dirt on the reflector surface over a two-month period, for example, might result in a significant loss in efficiency.

High temperature collectors do not necessarily collect more energy. They are designed to operate more efficiently at high temperatures, but at low to medium temperatures flat plate collectors often can collect more total energy—the working fluid is just not as hot.

There is only a certain amount of sunlight which falls in a certain area; focusing it into a point does not mean there is more of it. The cost and performance of high temperature collectors are justified only for applications which truly require high temperatures.

c. Catalog Cuts. The following are examples of collectors which typically represent their generic types. Inclusion does not imply a recommendation. Because the market is constantly changing, definite selections should be made closer to the time of construction.

Absorber plates for each generic type are available separately for site fabrication. Computer simulations contained elsewhere in this study used the Solar Energy Products, Inc., collector as a representative model.

The catalog cuts which follow are from:

Solar Development Incorporated (all-copper tube and plate, plastic glazing)

Sunworks (all-copper tube and plate, glass glazing)

Solar Energy Products, Inc. (copper flow tubes mechanically expanded into an extruded aluminum plate, glass glazing)

Alten Corporation (copper tube, aluminum plate, glass glazing)

PPG Industries, Inc. (all-copper or all-aluminum tube and plate, glass glazing)

Chamberlain Manufacturing Corporation (steel envelope plate, glass glazing)

Acurex Aerotherm (tracking parabolic trough collector)

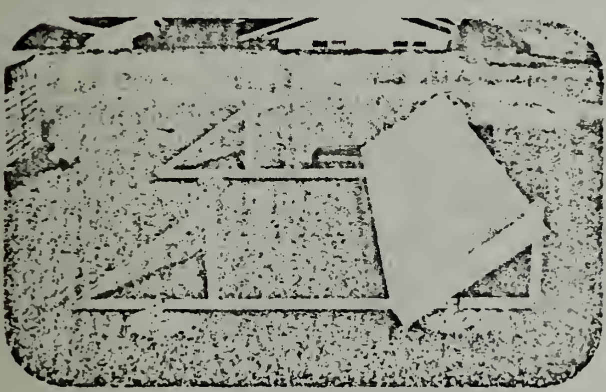
General Electric (evacuated tube collector)

Solergy, Inc. (non-tracking focusing collector).

SDI

SD5 SOLAR COLLECTOR

Space Heating   Swimming Pools   Domestic Hot Water



2'x10' dual mount

4'x10' horizontal

TECHNICAL SPECIFICATIONS

Note; Solar Collector mounted with long dimension vertical when using parallel absorber plate.

PIPING - 100 foot of ½" copper tubing, 4.6" on center, sinusoidal or parallel layout (vertical panel with headers top and bottom).

PIPE/PLATE CONNECTION - Absorber plate grooved to accept ½ of pipe circumference, 100% capillary flow solder bond.
- no thermal warping
- excellent heat transfer
- no low cycle fatigue

BOX - Extruded aluminum sides; .032" aluminum sheet metal backing (.019" for 2'x10' configuration).

COATING - High quality flat black black chrome available on special order.

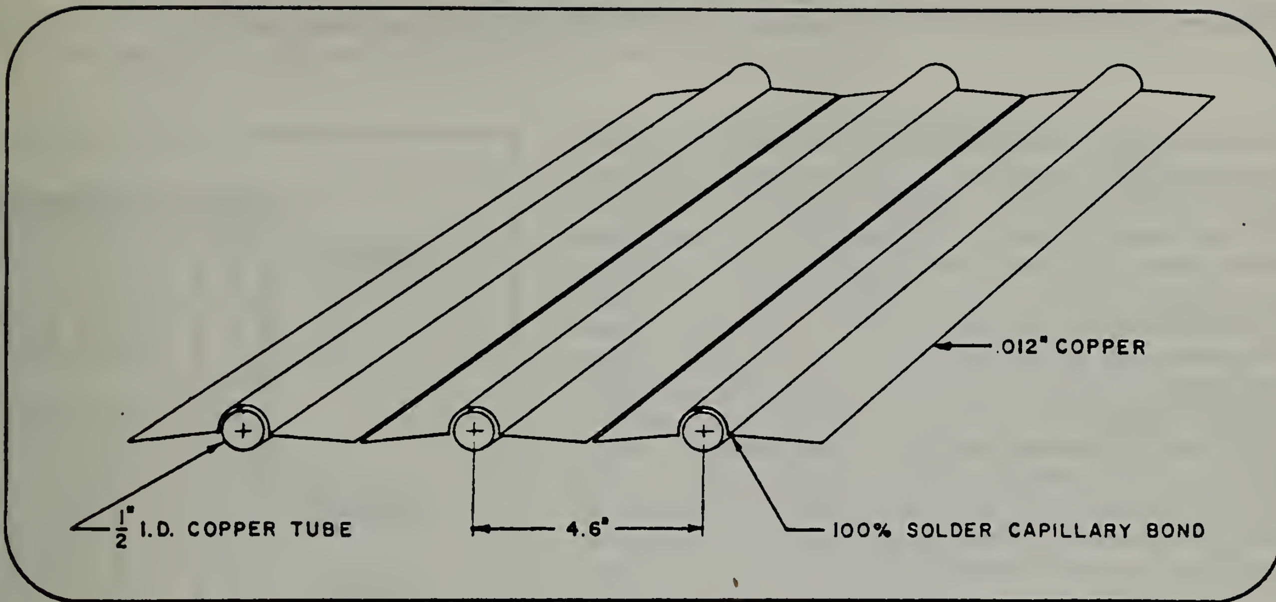
WIND LOADING - Designed for 30 lbs./ft^2

GLAZING - .025" Kalwall Sun-Lite Premium for 4'x10' panels; .025" Kalwall Sun-Lite Premium for 2'x10' panels and inner glazing of all double glazed panels.

VARIATIONS - Other lengths, widths, etc. can be built to meet specific requirements.

INSULATION - 1" technifoam isocyanurate (R = 9) or 2" technifoam isocyanurate (R = 18).

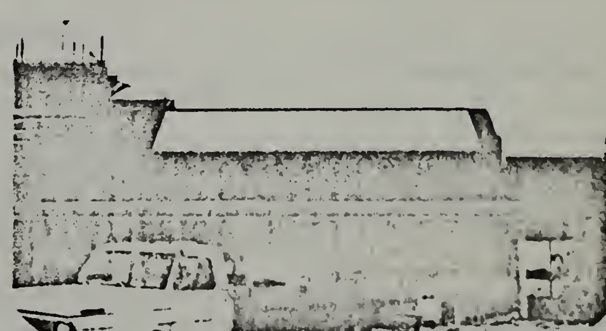
PERFORMANCE - The SDI collector has been tested by Desert Sunshine Exposure Tests, Inc., Black Canyon Stage, Arizona using The National Bureau of Standards' Test Procedure. SDI has a computer program to predict performance under various conditions based on the results of this testing. Large installations can be designed optimizing tank size and number of collectors.



Configuration	Dimensions	Layout	Glazing	Insulation	Weight	Price	Packing
(1)	4x10	sinusoidal	single	1"	110 lbs.		$12.00
(2)	4x10	sinusoidal	double	1"	118 lbs.		$12.00
(3)	4x10	sinusoidal	double	2"	126 lbs.		$12.00
(4)	4x10	parallel, ¾" headers	single	1"	110 lbs.		$12.00
(5)	4x10	parallel, ¾" headers	double	1"	118 lbs.		$12.00
(6)	4x10	parallel, ¾" headers	double	2"	126 lbs.		$12.00
(7)	2x10	sinusoidal	single	1"	57 lbs.		$ 6.00
(8)	2x10	sinusoidal	double	1"	61 lbs.		$ 6.00
(9)	2x10	sinusoidal	double	2"	65 lbs.		$ 6.00
(10)	2x10	parallel, ¾" headers	single	1"	57 lbs.		$ 6.00
(11)	2x10	parallel, ¾" headers	double	1"	61 lbs.		$ 6.00
(12)	2x10	parallel, ¾" headers	double	2"	65 lbs.		$ 6.00

F.O.B. West Palm Beach, Fla.


Attractive Vertical Mounting


320 sq. ft. Array

SDI

Solar Development Inc.
4180 Westroads Drive
West Palm Beach, Florida 33407
(305) 842-8935

P.O. BOX 1004 • NEW HAVEN. CONNECTICUT 06508 • (203) 934-6301

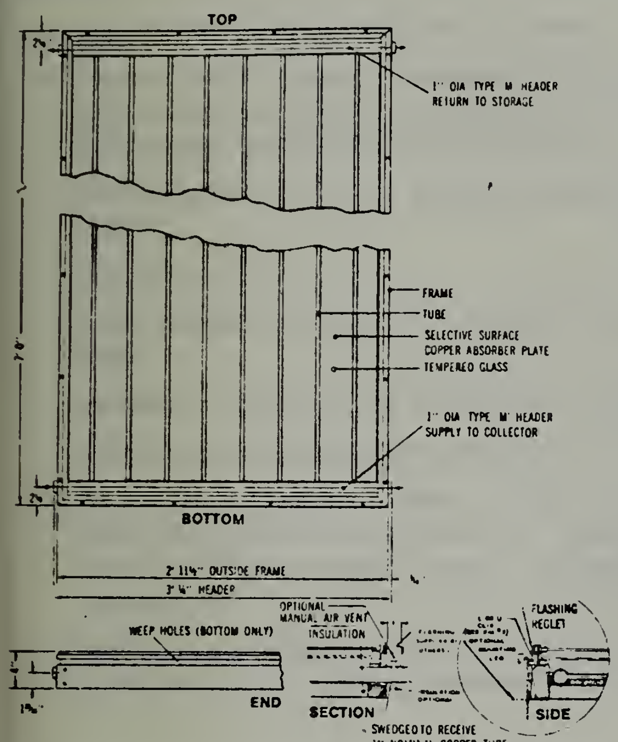


Figure 6

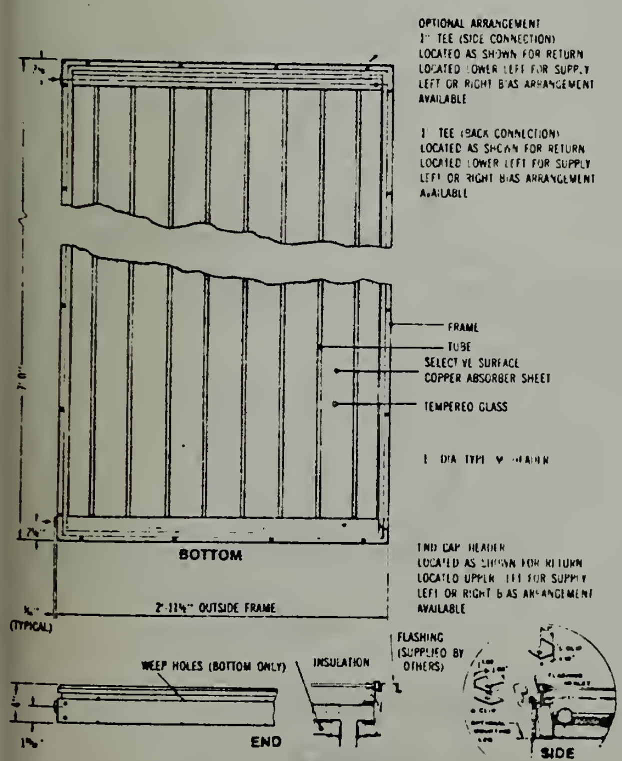


Figure 7

The 3′ x 7′ liquid cooled Solector solar energy collector, with internal manifolding and side or side/back connections allows for a multi-panel array to be coupled in parallel before returning to the main supply or return branch. This results in fewer field connections and fewer piping accessories while retaining a high installed net to gross ratio, approximately 88 percent. The internal header liquid cooled Solector is available with connection locations that allow side-by-side mounting for parallel flow or end-to-end mounting for series flow (See Figure 8 for typical plumbing arrangements). This new Solector configuration responds to the specific design requirements of solar collector arrays for commercial, industrial, and institutional building types by maximizing the amount of collectors able to be placed onto the structure while minimizing the installed cost. The optical and thermal properties as well as the physical design features of this new Solector basically parallel those of the standard liquid cooled Solector with the exception of the collector to collector connections and number of riser tubes.

Cover

- Single glazing: iron-free, 3/16 inches tempered, edges swiped.
- Double glazing: iron-free, 2-1/8 inch tempered, sealed unit with desiccant.
- Total transmissivity: Single glazing, 92 percent; Double glazing, 85 percent.

Absorber Container

- Sides, aluminum extrusion; rear aluminum sheet 0.05 inches thickness, pop rivet in place.

Air Space Between Cover and Absorber

- Approximately ¾ to 1 inch depending upon glazing type.

Gasketing Material

- Neoprene "U" gasket for glazing, closed cell elastomer, compressible high temperature silicone seal for absorber sheet.

Weatherproofing

- This module can be placed out in the weather without need for further weatherproofing.

Finish on Aluminum Sides of Container

- Standard mill finish, anodized clear or baked black enamel (available at extra cost).

Dimensions of Surface-Mounted Module

- Outside dimensions overall: 35½ inches wide x 64 inches long or 84 inches long x 4 inches thick (add 1¼ inch each end for optional continuous mounting bracket).
- Effective absorber area = 18.50 ft² for 3′ x 7′ unit.
- Ratio of usable absorber area to total installed surface covered = 0.88.
- Glass area (aperture) = 18.88 ft².

Absorber

- Copper sheet: 0.010 inches thick (7 ounces).
- Selective black: minimum absorptivity, .87/.92; maximum emissivity, .07/.35. Manufactured by Enthone, Incorporated; guaranteed durable to 400°F.
- Copper tubes: ⅜″ O.D., 4 inches on center, L-type copper.
- Tube pattern: grid.
- Bond between tube and sheet: high temperature solder.
- Manifolds: 1 inch ID (1.125 in OD) M-type copper.
- Tube connections to manifold: brazing alloy.
- Connection to external piping: 1 inch I.D. (1.125 inches O.D.) M-type copper tube. See Figures 6 and 7 for manifolding options. Type of connections to be specified.
- Manifold/tubes pressure tested before leaving factory to 15 atm; 125 psig working pressure.

Insulation Behind Absorber

- 1 inch thick glass fiber (compressed) over 1.0 inch thick foil-faced isocyanurate, R = 10.0, (glass fiber, 1.2 lbs/ft³ density).

Method of Anchoring

- Keyway integral to collector frame continuous along perimeter of frame designed to accept "L" or "U" clips with predrilled ⅜″ diameter hole for bolt mounting to roof or frame. Optional 1¼ inch mounting leg integral with top and bottom of frame; four ⅜″ diameter holes predrilled. Capability of through bolt anywhere along its length.

Weight Per Module

- 114 pounds, filled; 111 pounds, empty (standard 3′ x 7′ unit). Add 27 pounds for double glazed unit. (NOTE: The liquid in the collector is equal to 0.36 gallons or 46.4 ounces or 2.90 pounds or 0.05 ft³ or 80.5 inches³).

Recommended Flow Rate Through Collector

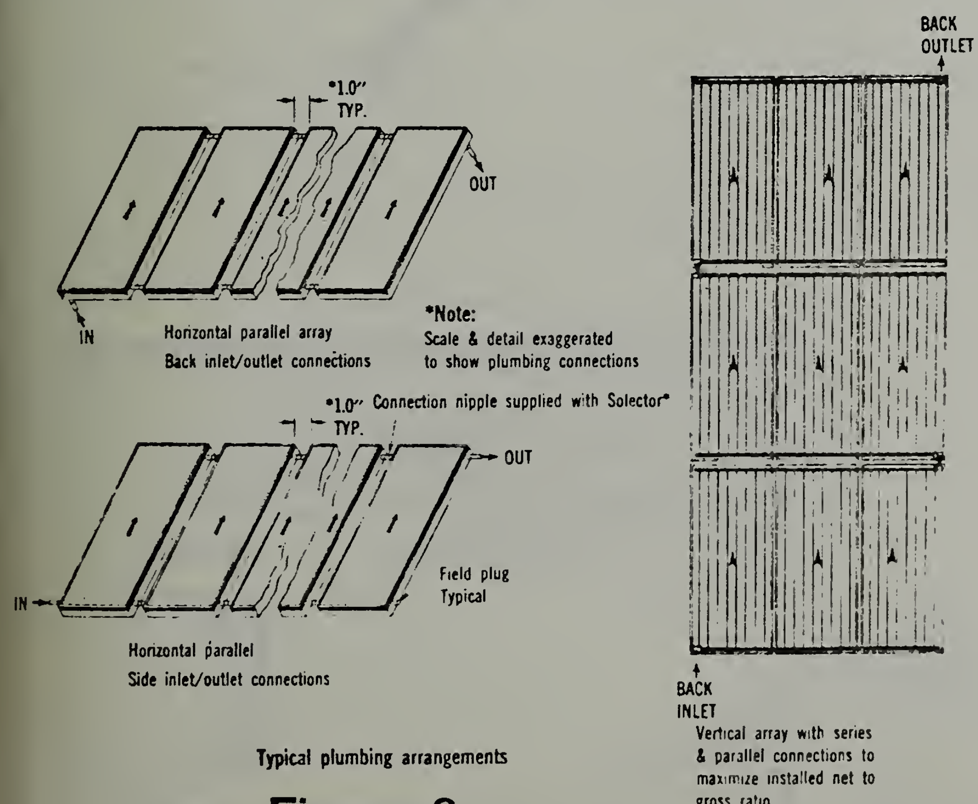
- 28 lbs/ft²/hr (1 gpm) per collector. For mean temperatures of 100°F using Sunsol 60, single glazed Fr = .91, double glazed Fr = .94. (Flow resistance at this rate is negligible.) (See Figure 4.)

Collector Coolant

- Coolant should be Sunsol 60, made by Sunworks. In areas where regular tap water is used as a coolant, it is important that the pH be controlled between 6.5 and 8. These collectors can be used with other coolants, but the user must contact the manufacturer for approval of specific liquids. (See guarantee statement available from Sunworks representatives.)

Five year material workmanship warranty on all parts except glazing. See your local Sunworks representative for details.

NOTE: THIS DATA SHEET INCOMPLETE WITHOUT SUNWORKS SOLECTOR BROCHURE.



Typical plumbing arrangements

Figure 8

See your Sunworks Representative for pricing and shipping.

Solar Energy Products, Inc.
1208 N.W. 8th Ave. • Gainesville, Florida 32601
Supplier of Solar Energy Equipment

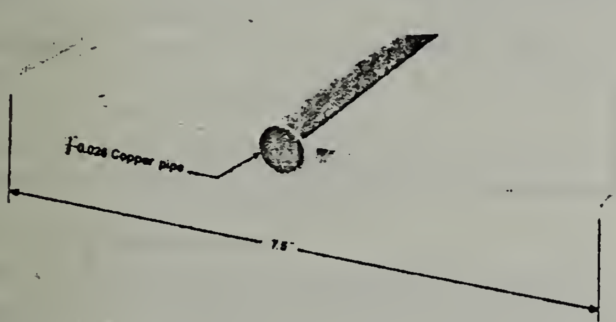
INTRODUCTION

SOLAR ENERGY PRODUCTS, INC. is actively promoting the solar energy industry by supplying a full product line of high quality equipment at the lowest possible cost. We have been actively involved in the research, development, manufacturing, and marketing of the equipment required to meet the increasing demand and expanding applications of the solar energy industry. The illustrated catalogue of **SOLAR ENERGY PRODUCTS, INC.** describes our varied product line of solar collectors, cover plate options, absorber plates, heat exchanger, pumps, differential temperature controllers, fluid handling packages, storage sub systems, mounting systems, specialty hardware, and pre-packaged solar water heating kits.

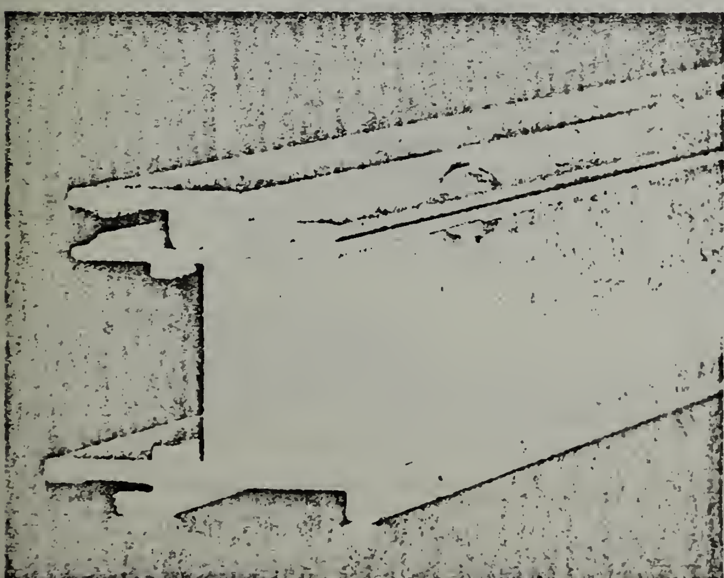
Our product line is designed to provide reliable performance of durable components that are easy to install and service. The catalogue describes the combinations of optional equipment available to the design engineer to co-ordinate the system performance into the various building designs to satisfy the regional requirements for the diverse applications of utilizing the sun's energy.

Our product line may be applied to the solar-thermal collection, storage and distribution techniques of water heating, space heating, pool heating, cooking, drying, space cooling and refrigeration for residential, commercial and industrial solar requirements.

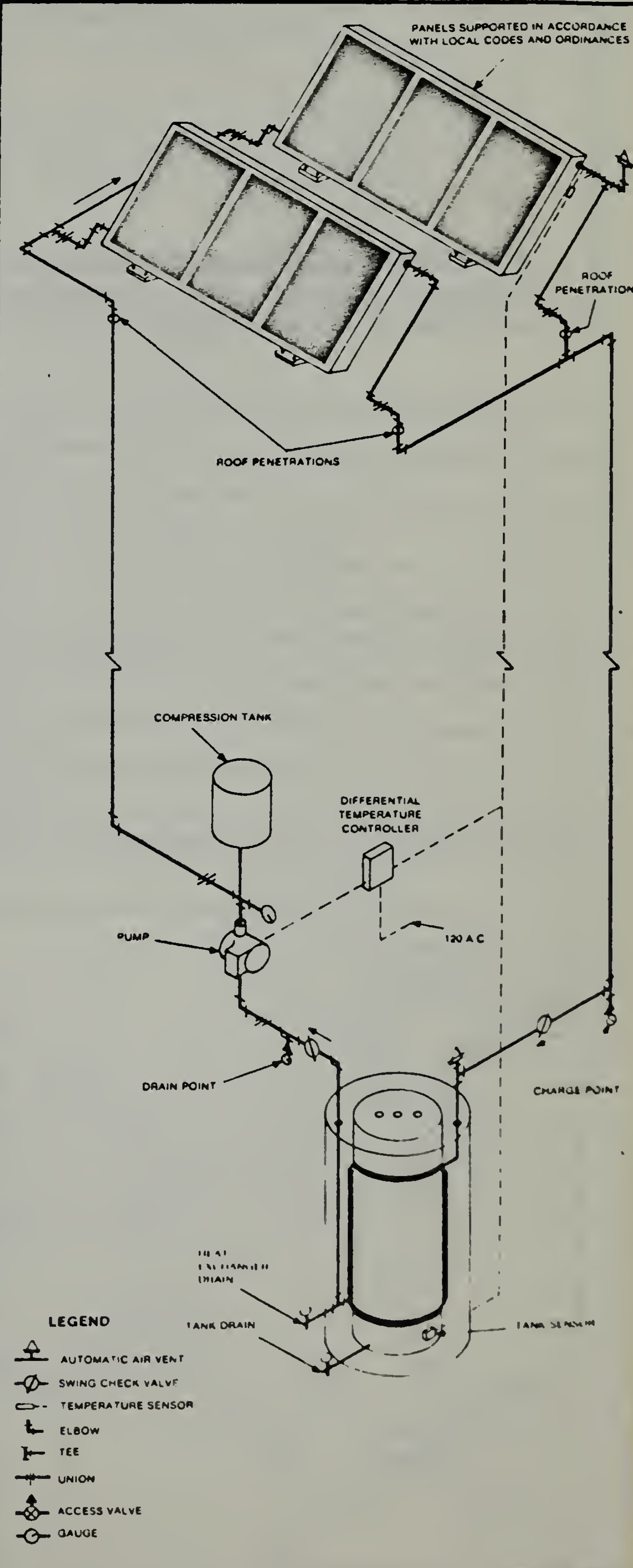
Our product line has been designed and developed to meet the performance criteria outlined by the **INTERMEDIATE MINIMUM PROPERTY STANDARDS FOR SOLAR HEATING AND DOMESTIC HOT WATER SYSTEMS (NBSIR-76-1095) AND THE INTERIM PERFORMANCE CRITERIA FOR SOLAR HEATING AND COMBINED HEATING/COOLING SYSTEMS AND DWELLINGS (HUD 1/1/75).**



ABSORBER PLATE



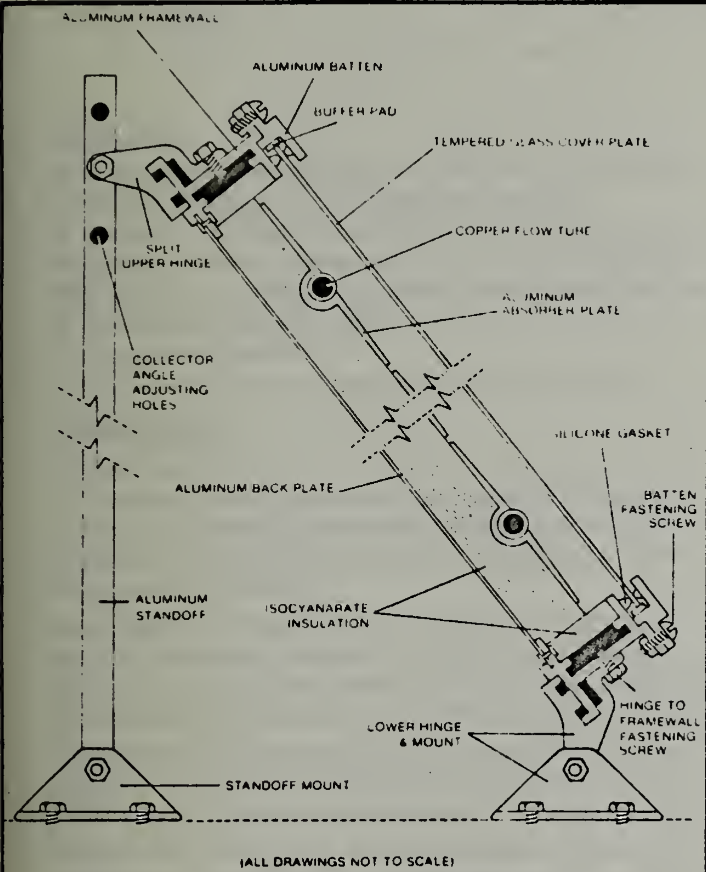
FRAMEWALL



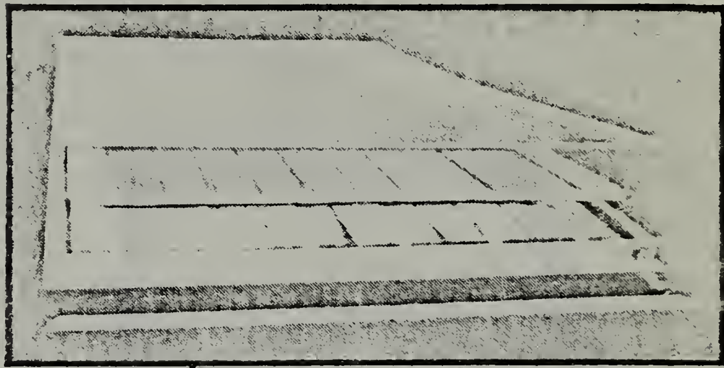
TWO PANEL DOMESTIC WATER HEATING SYSTEM

Solar Energy Products, Inc.
1208 N.W. 8th Ave. • Gainesville, Florida 32601
Supplier of Solar Energy Equipment

SPECIFICATIONS: CU30 FLAT PLATE SOLAR COLLECTOR



CROSS SECTION OF PANEL & MOUNTING SYSTEM

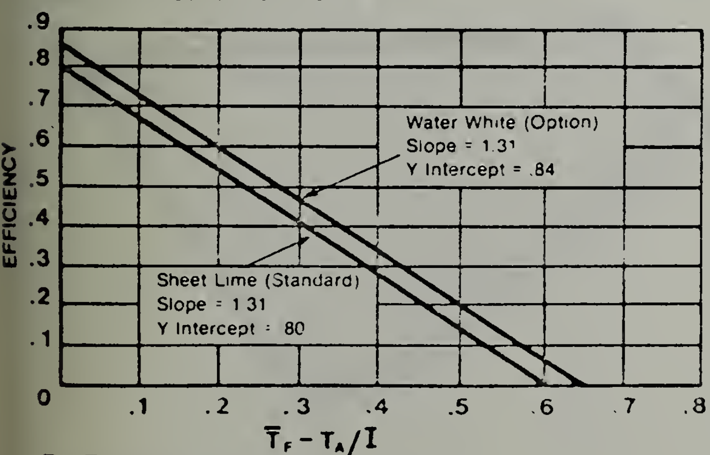


EXPLODED END VIEW OF CU30 COLLECTOR

THE CU30 FLAT PLATE SOLAR COLLECTOR is designed and built with care and precision for:

- Dependable Performance, when properly operated for a minimum of 30 years.
- Excellent Thermal Performance for a single glazed, modified grid, flat plate solar collector
- Thermal Performance Stability to 300°F
- Use in open and closed circuit system with working pressures to 150 psi.
- Use with any heat transfer fluid compatible with copper.
- Flexibility of mounting, either fixed or adjustable, through the use of positionable hinges.
- Simplified field servicing by complete component access through front.
- Use in anti-freeze, dump or recirculation freeze protection systems.
- Ease of hookup with standard copper plumbing components and practices.
- Compliance of standards as set by NBSIR 76-1059, NASA 98m-1001, and all known codes affecting solar collections equipment.
- High structural integrity in wind loads to 130 mph.

THERMAL PERFORMANCE CURVE:

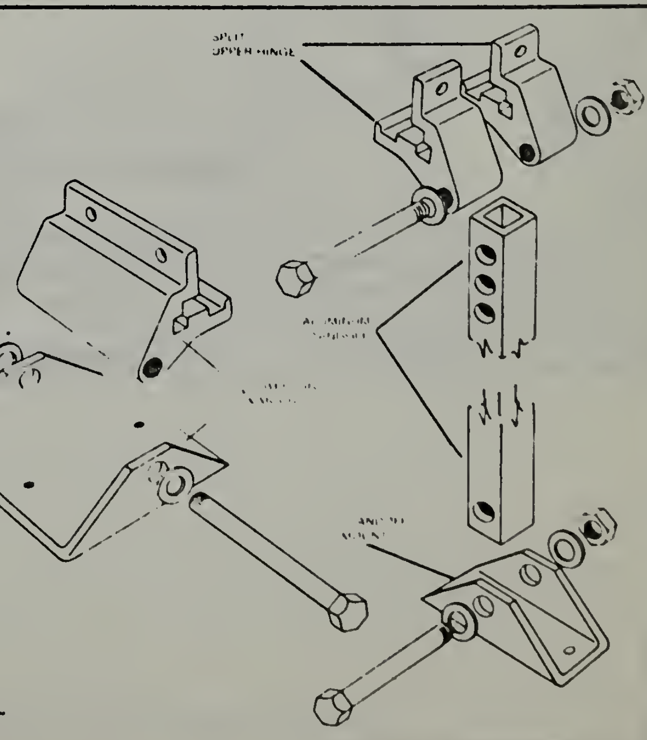


$\bar{T}_F = \frac{T_{IN} + T_{OUT}}{}$ of collector fluid
T_A = Typical ambient temperature in their area
I = Typical insolation in their area striking panel

THERMAL PERFORMANCE STABILITY: Thermal distortion of the solar collector during operation and periods of stagnation to temperatures of 300°F will not cause significant deterioration of panel's performance.

Testing performed in accordance with NBSIR 74-635 by Energy Design Associates, Inc., Gainesville, Florida.

Testing performed in accordance with ASHRAE 93-P and NBSIR 74-635 by Desert Sunshine Exposure Tests, Inc., Phoenix Arizona.



CORPORATION

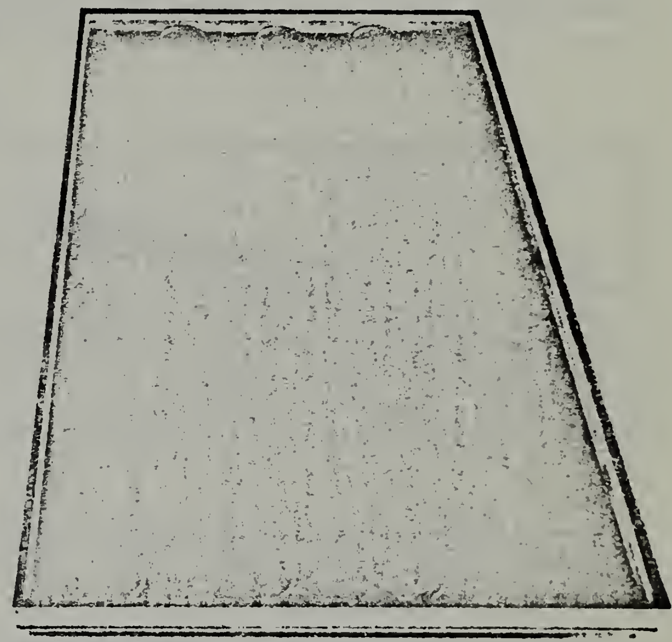
The Alternate Energy People

Solar Collector Panels

Features

- A model for every application, residential or commercial
- Designs proven in actual operation since 1974
- Corrosion-resistant copper in all water passageways
- Unique vertical fin design provides maximum absorptivity
- Rugged extruded aluminum frame makes installation easy
- Exceptional temperature uniformity
- Ten year warranty*

*See complete warranty statement for terms and conditions.



Alten Model 200G Solar Collector Panel

Description

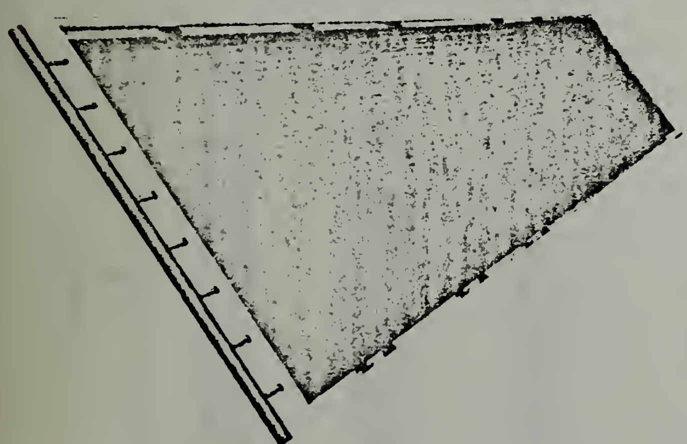
A Complete Line

The Alten family of solar collectors gives architects and contractors a choice of job-matched panels to meet any requirement, from pool heating to air conditioning. Three basic panels are available:

Model 200G: A high efficiency, double-glazed, flat plate collector specifically designed for high temperature applications like solar radiant baseboard heating and air conditioning. Typical output temperatures are in the range of 150 to 200°F.

Model 100G: A single-glazed version of the 200G, designed for lower temperature uses (output temperatures of 120 to 140°F), such as general space and water heating applications.

Model 110F: A low cost, single-glazed collector specifically designed for low temperature applications (output temperatures of 90 to 130°F) like year-round swimming pool heating and industrial water preheating. An un-insulated version, Model 110FU is also available.



Alten Model 110F Solar Collector Panel

Designers, developers and installers of solar heating/cooling systems for industry, institutions and homes.

Proven Designs

Alten solar panels incorporate performance and convenience features proven to be of value under actual operating conditions in the many solar heating systems installed by Alten since 1974 (reference list on request).

For example, the absorber used in Alten panels combines the excellent heat transfer, weight and structural properties of aluminum extrusion with the outstanding corrosion resistance of copper tubing. The result is one of the most efficient and cost effective absorbers possible.

Single tube construction of water passageways is another advantage of all Alten panels. There are no solder joints or corrosion pockets. Models 200G and 100G have a continuous, serpentine copper tube. The Model 110F uses several, one-piece, straight tubes.

High Efficiency Collection

Unique vertical absorber fins in Alten solar panels provide very high absorption of the primary sunlight and increase total absorptivity to 99 percent. This is shown graphically in Figure 1. Fins are located at precisely calculated intervals to minimize thermal losses caused by convection currents inside the panel. Collection efficiencies for the various panels under different insolation conditions are shown in Figures 2, 3 and 4. In addition, Figure 5 compares the hourly collection performance of all 3 Alten panels and Figure 6 shows daily heat collection at different tilt angles, using the 100G panel as a reference.

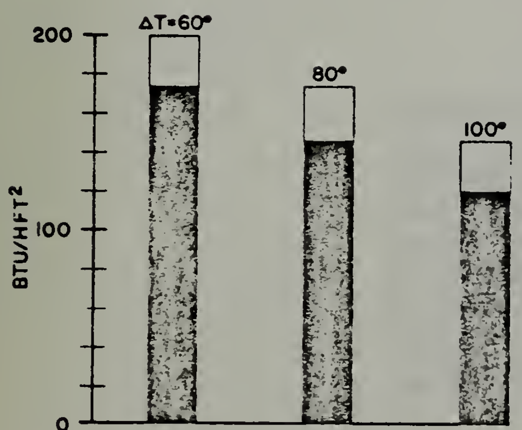


Figure 1: Significance Of High Absorptivity
Solar collectors typically have an absorber coating with 90% absorptivity. The energy output of an Alten Collector having 99% absorptivity, is shown by the white bars. The solid bars show the collection obtained by a typical panel having a 90% absorptivity coating under identical conditions, the differences being strictly the effectiveness of the absorber coating.

Easy Installation

Alten solar panels are easy to install because of their rugged structural aluminum frame. They can be mounted directly, as a weatherproof roofing substitute, or they can be flush mounted on existing surfaces. Unique metal mounting brackets are available for panel mounting at any angle to the roof surface.

Exceptional Temperature Uniformity

Temperatures across Alten solar panels are highly uniform to ensure even, efficient heating. For example, under average operating conditions (200 BTU/h ft^2 collection) the temperature difference between any point on the extruded aluminum absorber and the nearest copper tube is less than 6°F. This is

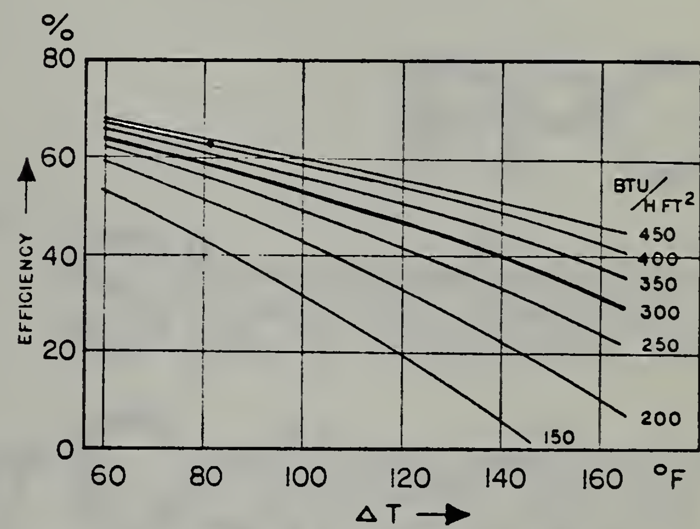


Figure 2: Model 200G Efficiency Under Various Insolation Conditions*
The outstanding performance of the Model 200G in the high temperature range (ΔT higher than 80° F) makes this panel ideal for use where output temperatures near the boiling point of water are needed at high efficiency. Typical applications include absorption solar air conditioning (typical ΔT range of 100 to 140° F) and radiant baseboard heating.

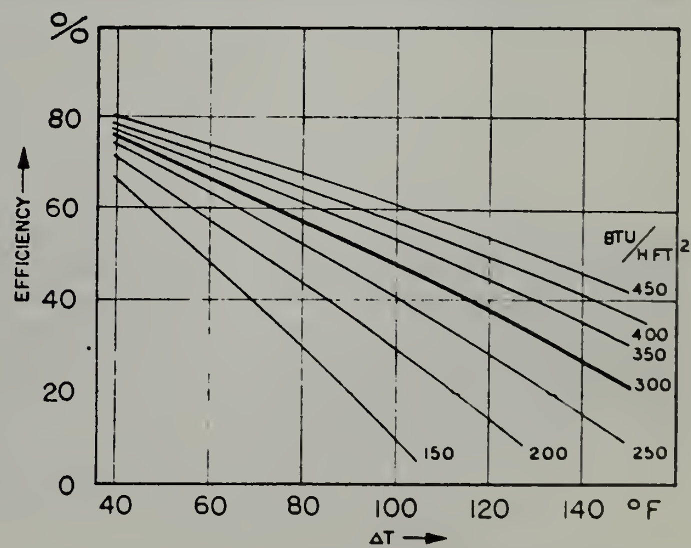


Figure 3: Model 100G Efficiency Under Various Insolation Conditions*
The outstanding performance of the 100G Collector in the medium temperature range (ΔT up to 80° F) makes this panel ideal for domestic water preheating and heating, as well as space heating and industrial process heating applications in most areas of the United States.

*Insolation values above 300 BTU/H FT^2 on the absorber surface area are obtainable by using reflectors adjacent to the collector.

Glass PPG INDUSTRIES

March 1, 1976

PPG Standard Solar Collector

GENERAL INFORMATION

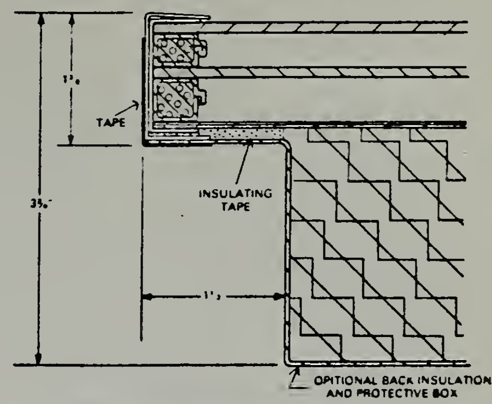
INTRODUCTION

Using years of research as a base, PPG has aggressively moved into the production of flat-plate solar collectors and the development of techniques to integrate PPG solar collectors into solar energy systems.

PPG started production of a Baseline Aluminum Solar Collector in 1974. Recently, PPG has introduced a Standard Copper Solar Collector.

PPG Standard Solar Collectors, aluminum and copper, are now functioning in solar energy systems that range from simple hot water heating to complex space heating and cooling.

Figure 1 — Typical Edge Section of PPG Standard Solar Collector



GENERAL DESCRIPTION

PPG Standard Solar Collectors are available with:

(1) One (1) or two (2) clear $\frac{1}{8}$-inch glass cover plates. These cover plates are heat treated for improved breakage resistance.

(2) A coated metal absorber plate with fluid carrying passages.

(3) Back insulation and a protective box (optional).

(4) Unit Size: $34\frac{3}{16}$" x $76\frac{3}{16}$" x $1\frac{3}{8}$" (without optional back insulation and box).

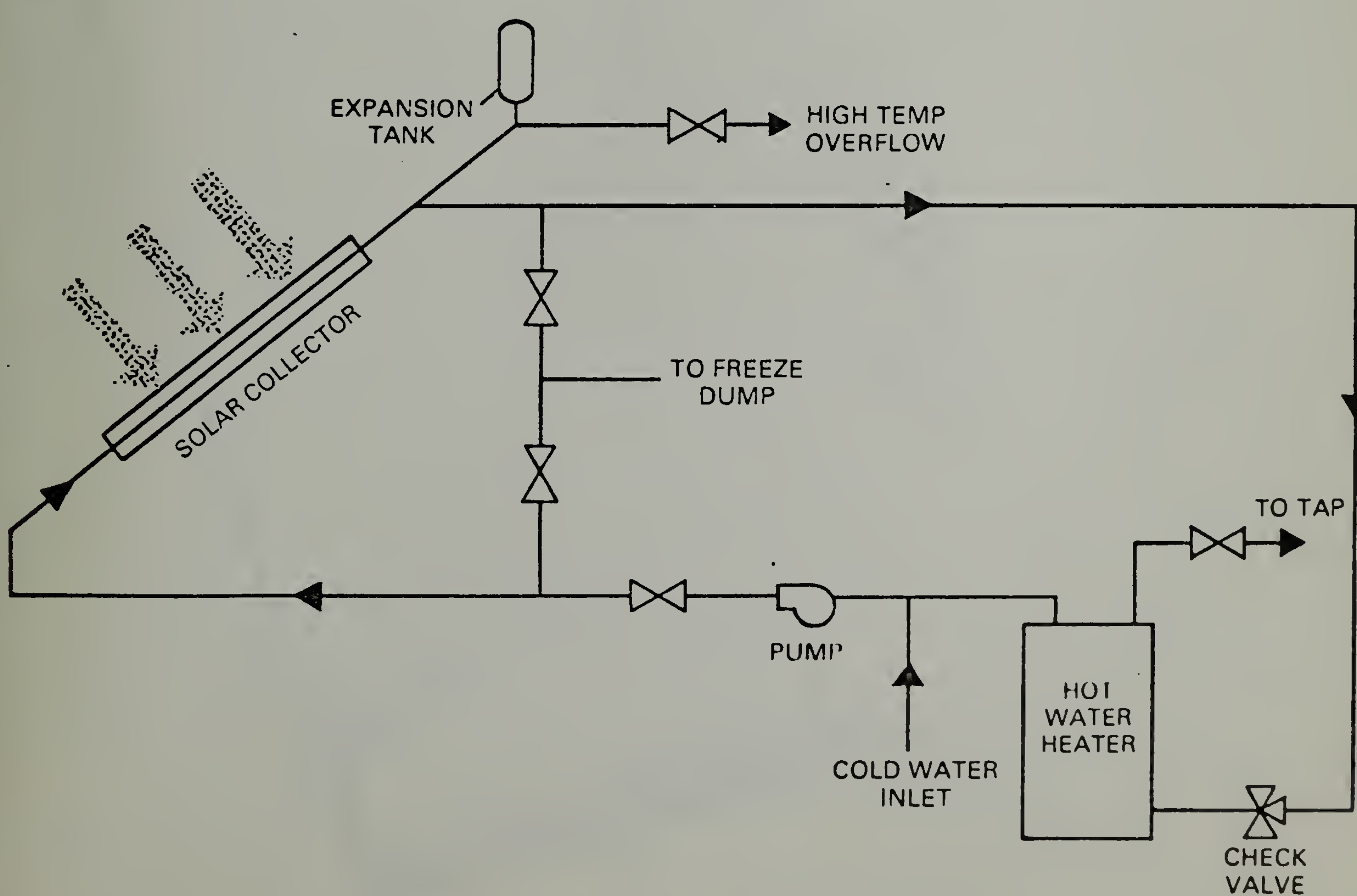
High quality PPG Standard Collectors are factory fabricated and sealed to preclude internal condensation. Figure 1 illustrates a typical edge section of a two-glass cover plate PPG Standard Solar Collector.

APPLICATIONS

PPG Standard Solar Collectors are used to gather solar energy which, in turn, may be used for heating domestic hot water, swimming pool water, structures, industrial processes, etc. PPG Standard Solar Collectors also provide excellent support for solar assisted heat pump systems, and can be used as heat generators for absorption air conditioning systems.

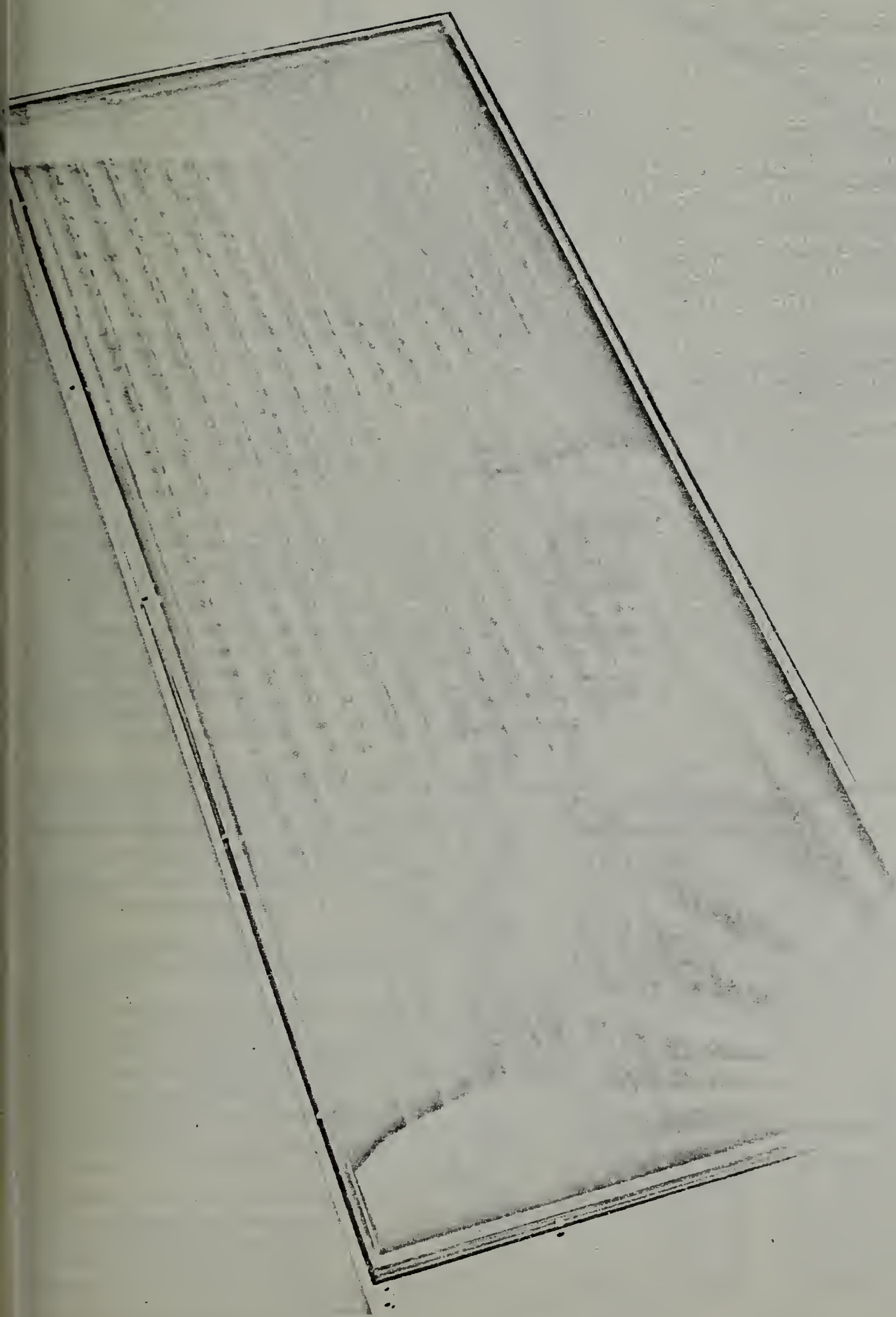
The following diagrams, Figures 2, 3, and 4, illustrate some typical solar energy systems which utilize PPG's Standard Solar Collector.

Figure 2 — Solar Hot Water Heating, No Storage



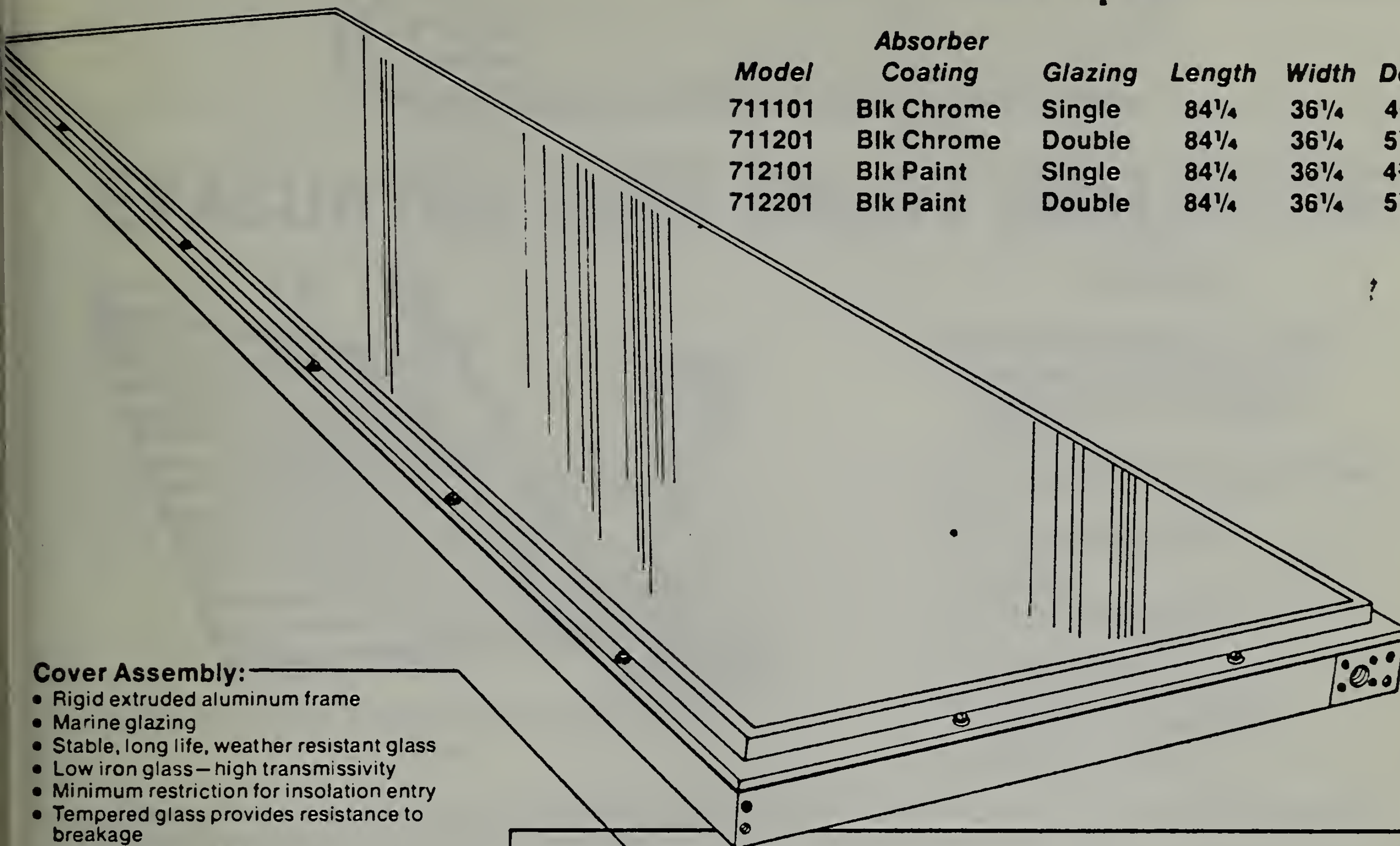
Chamberlain

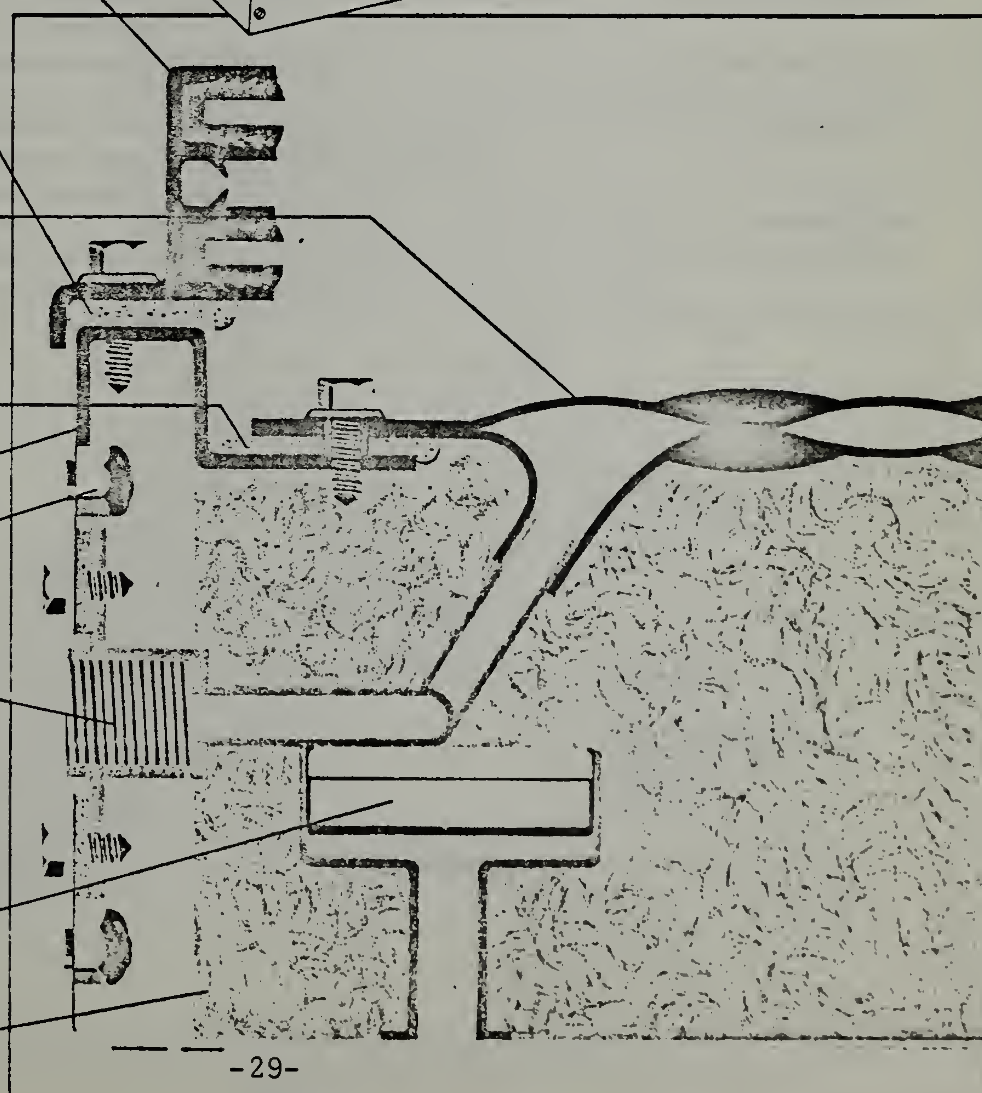
Solar Collector Panels



Features and Specifications:

Model	Absorber Coating	Glazing	Length	Width	Depth
711101	Blk Chrome	Single	$84\frac{1}{4}$	$36\frac{1}{4}$	$4\frac{3}{8}$
711201	Blk Chrome	Double	$84\frac{1}{4}$	$36\frac{1}{4}$	$5\frac{1}{16}$
712101	Blk Paint	Single	$84\frac{1}{4}$	$36\frac{1}{4}$	$4\frac{3}{8}$
712201	Blk Paint	Double	$84\frac{1}{4}$	$36\frac{1}{4}$	$5\frac{1}{16}$





Cover Assembly:
- Rigid extruded aluminum frame
- Marine glazing
- Stable, long life, weather resistant glass
- Low iron glass—high transmissivity
- Minimum restriction for insolation entry
- Tempered glass provides resistance to breakage
- Serviceable in the field

Cover Gasket:
- Provides seal between cover and box
- Thermally isolates absorber cavity from metal parts exposed to atmosphere
- Resilient, long life material

Steel Absorber Plate:
- Maximum wetted surface
- Minimum flow resistance
- Rugged steel construction
- Pressure tested
- Selection of coatings available

High Temperature Insulating Strip:
- Insulates absorber plate from frame

Absorber Support:
- Rigid support bracket welded to side of box

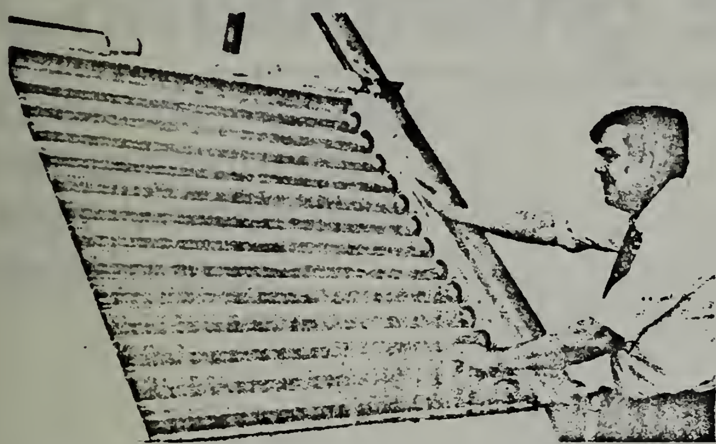
Mounting:
- Two 5/16" weld nuts each corner
- Rigid
- Easy to adapt to any support
- No projections—will not become damaged in shipment

Piping Connection:
- ½" Female iron pipe thread
- Flush mounted—avoids shipping damage
- Uses standard pipe fittings
- Thermally insulated from box
- Ruggedly attached to box—allows for heavy handed plumbers
- Isolates absorber plate from external piping movement

Desiccant:
- Controls moisture in absorber cavity
- Minimizes condensation on glass
- Regenerated by absorber plate heat

Insulation:
- High temperature Fiberglass insulation
- Maximum insulation with minimum volume

EVACUATED TUBE SOLAR COLLECTOR



Evacuated Tube Collector Engineering Development Unit Test Program

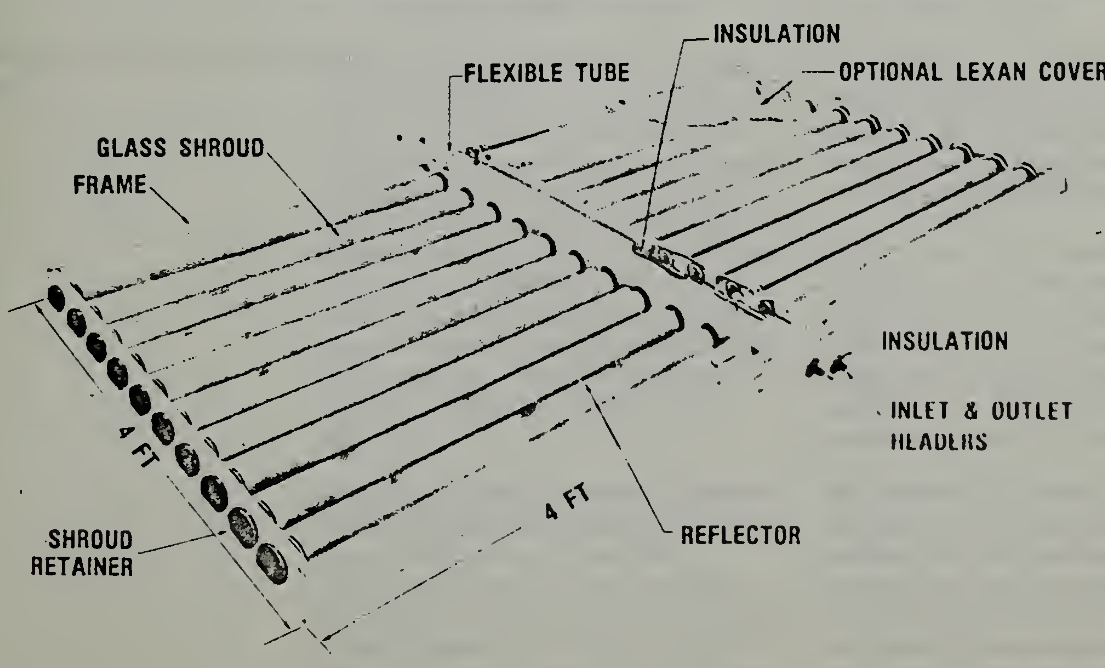
FEATURES

- HIGH TEMPERATURE: 200° - 300°F
  - LESS ENERGY STORAGE VOLUME
  - GREATER COOLING EQUIPMENT EFFICIENCY
- HIGH EFFICIENCY AT HIGH TEMPERATURE
  - SMALLER SYSTEM AREA
- HIGH BTU/$
  - LOWER SYSTEMS COSTS
- HIGH RELIABILITY
  - ALL METAL FLUID SYSTEM
  - NO GLASS–TO–METAL SEALS
  - SLIP–ON GLASS TUBES

General Electric is introducing an innovative solar collector that provides up to twice the energy collection capability of the double glazed, selectively coated, flat plate collector.

This advanced evacuated tube design uses conventional GE fluorescent lamp tubes fabricated into a "thermos bottle" unit. Each of the tubes lies within a tray which serves as a concentrator, reducing costs while generating high temperatures at low insolation values. Thermal energy is removed from the glass tubes by an independent fluid system, entirely contained in metal, which allows the system to continue operating even in the event of tube breakage.

The high temperature performance of the evacuated tube collector means lower systems cost due to smaller collector area and smaller thermal storage requirements; greater cooling equipment efficiency; as well as opening new opportunities in the area of process heat and space heating and cooling. An additional advantage is the greatly increased solar operating period gained because of the collectors' good performance under adverse solar and environment conditions.

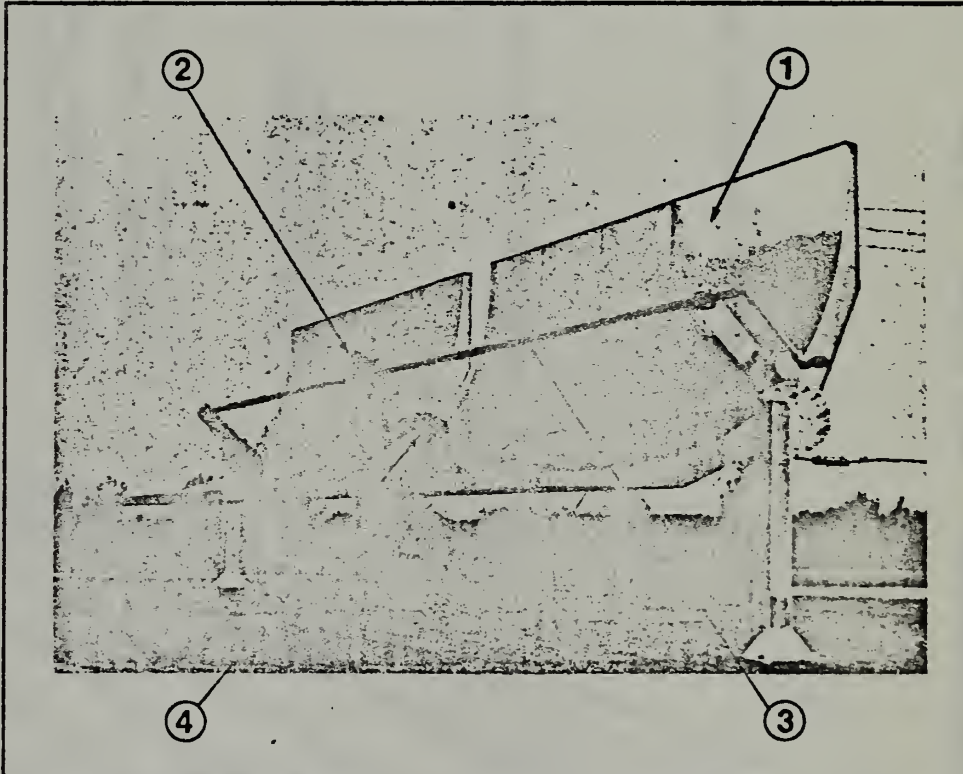


Artist Concept of Evacuated Tube Collector Production Model

ACUREX
Aerotherm

Model 3001 High-Temperature Concentrating Solar Collector

Low-cost, versatile concentrator for high-temperature applications.



1 — Reflecting Lighting Sheet
2 — Shadow Band Tracker
3 — Absorbing Receiver Tube
4 — Motor Drive

Description

The Model 3001 Acurex Concentrating Collector is a reflecting parabolic trough solar collector. It is designed to heat liquids or gases to temperatures between 250°F and 600°F. In this temperature range, the Acurex Collector is highly cost-effective compared to other flat-plate and concentrating collectors now on the market. Typical applications include water heating, air heating, steam generation, and space cooling.

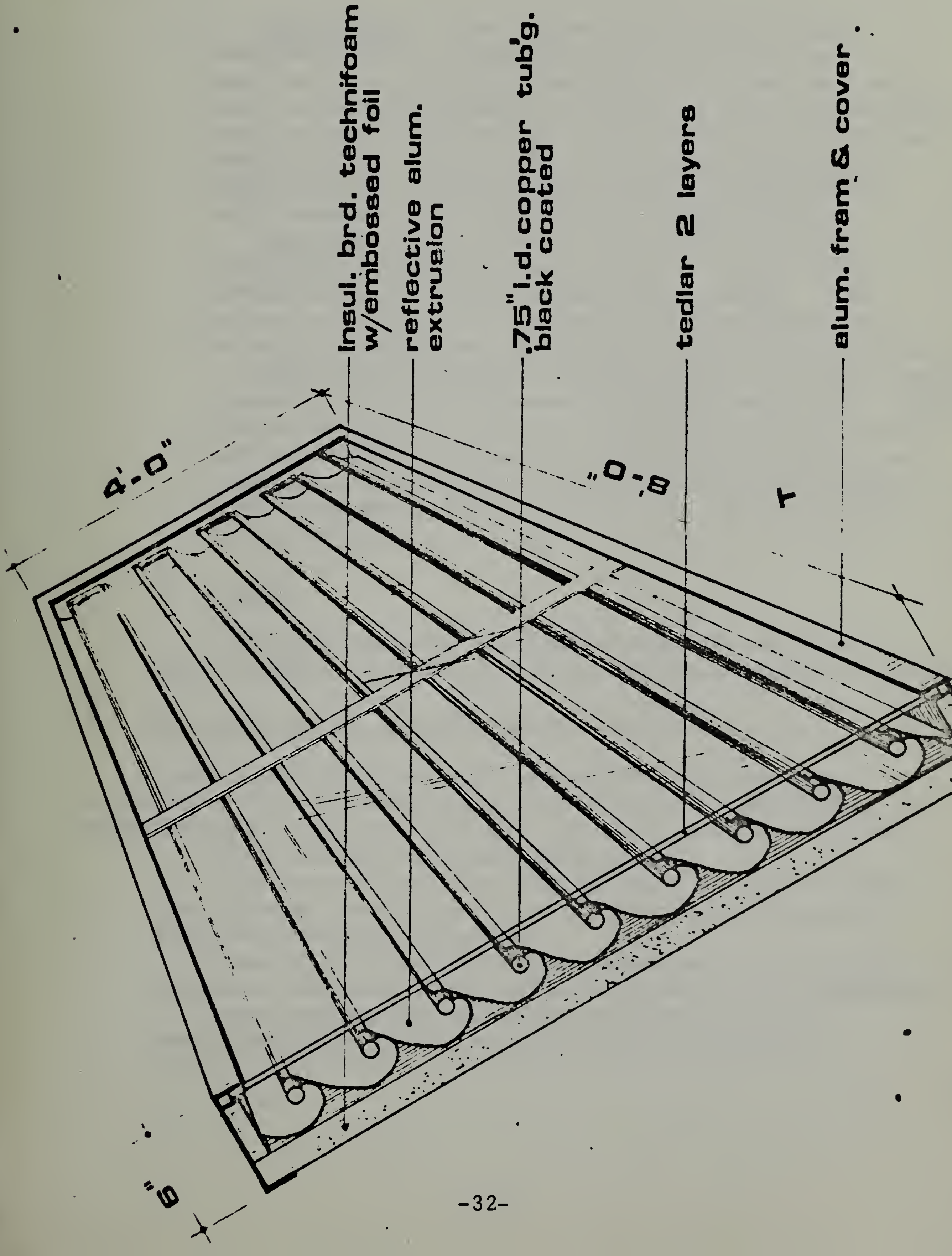
The Model 3001 Collector is assembled in modules 10 feet in length. Eight modules are normally coupled togther to form a line of collectors which is driven by a single drive system at the middle of the line. This arrangement can be modified to suit any specific application.

The aperture of the reflecting parabolic trough is 6 feet with a rim angle of 90°. The reflecting surface is aluminum lighting sheet mounted on a painted structure.

Each collector is equipped with a 1.25-inch mild steel receiver tube. This receiver tube is coated with either black paint or selective black chrome over nickel plate (for applications over 250°F). A pyrex glass jacket encloses the receiver tube.

The heated fluid in the receiver tube can be water, organic liquid, or air. A central plug in the receiver tube creates an annular passage that produces high liquid convective coefficients with an acceptable fluid pressure drop. The size of the plug is based on the specifications of the overall system.

SOLERGY, inc.
70 ZOE STREET SAN FRANCISCO, CALIFORNIA 94107
(415) 495-4303



SOLERGY COLLECTOR 1-AT-48

d. Storage

Water Storage. There are two types of water storage tanks which could potentially be used: (1.) Pressurized tanks for use in storing potable domestic hot water are usually steel and lined with fiberglass or cement, and (2.) Unpressurized tanks, considerably larger, are used to store hot water for space heating systems. These tanks are generally constructed of either reinforced concrete, steel or fiberglass, lined with a water membrane, and installed above or below ground.

Rock bed storage systems are used with air collectors. Construction materials are similar to those used for water storage; obviously, waterproofing is not as critical. Rock bed storage systems are considerably larger in volume than hot water storage systems for the same amount of energy stored.

Heat of Fusion Storage. At present, the use of phase-change storage systems is in the research and development stage. These systems use materials such as salt hydrates and parafin which melt and solidify at temperatures used for solar collection and distribution. These systems, which utilize the heat of fusion, require considerably less space than either water or rock bed storage systems.

e. Controls

Controls for collection and distribution in solar systems are readily available, completely automatic and require little maintenance.

3.2 Solar Domestic Hot Water Heating and Space Heating

Domestic hot water heating and space heating offer the best opportunities for active solar applications at the airport, from both technological and economic standpoints. The reasons for this are that:

—they represent substantial energy loads.

—they require temperatures that are easily achieved with flat plate collectors, making them more economically and technically attractive than other applications.

—their interface and heat transfer requirements are relatively simple and utilize traditional mechanical techniques and equipment.

—they represent the most common of solar applications, making their performance more predictable and dependable.

a. Combination versus Split Systems. Space and water heating requirements can be achieved in a combined solar system which shares collection and storage facilities, but operates with separate distribution loops, or in separate systems which operate independently of each other, utilizing their own collection, storage and distribution systems.

The advantages of a combined system are:

—a single loop between storage and collectors.

—a single storage tank, whose heat can be used for either system.

—extra capacity for one system when the other is' not needed, such as in the summer when space heating is not required; the excess collection can be used for domestic hot water heating.

The advantages of split systems are:

—they need not be installed at the same time.

—they make possible a domestic hot water system which pumps potable water through the collectors, eliminating the need for a heat exchanger and increasing system efficiency.

—they allow for different operating temperatures.

b. Liquid versus Air Systems. For domestic hot water systems, a solar water system is an obvious choice. For space heating, air systems present storage and duct size complications and additional costs in interfacing.

c. Solar Domestic Hot Water Heating. As shown in Figure 3.2.1 this system is a pressurized system in which potable water flows directly through the collectors, so no heat exchanger is required.

When the collector temperature is higher than the storage tank temperature, a pump is activated which circulates water from storage through the collectors and returns to storage. As a water load occurs, hot water is drawn off the top of the tank. From there it passes through the existing heat exchanger, which will add more heat to the water if necessary and then continues to its use point. The back-up heat exchanger is supplied with heat from the primary heating loop.

A similar but smaller system, with little or no storage, could operate as a preheater during the daylight hours only.

In these systems, water remains in the collectors at all times, exposing them to the hazards of freezing. Freezes occur an average of three times a year at the airport, but because the collectors are usually colder than the ambient air at night due to night sky radiation, they will reach freezing temperatures more often. If water in the collectors freezes, the ice will expand and burst the collectors. It only takes one freeze to destroy a whole collector system. There are several methods available for protection:

—A thermic valve will open at a set temperature (35°F.) allowing water to flow through the collector and out a drain. These valves operate mechanically (no electricity required).

—A freeze sensor can be used on the controller which will turn on the pump whenever the collector nears freezing. In this way, the collectors are warmed by heat from the storage tank. This inefficiency is tolerable for a location like San Francisco where freezes are rare. This system will fail if there is a malfunction in the controller, or the pump, or during power failures which tend to happen during extreme weather conditions.

—Electric heat tape can be placed on the absorber plate to keep it above freezing temperatures, but this would be undesirable if prefabricated collectors were used. This also would not function during a power failure unless a battery were incorporated.

—With the use of automatic valves, the collectors can be isolated to drain every night, or only during freezes and power failures. This system relies on the dependability of the automatic valves. It can waste a lot of water if it is designed to drain every night since it is difficult to drain into the pressurized storage tank.

—A combination system using both a freeze sensor and an automatic valve for drain-down in case of a power failure is a relatively fail-safe compromise.

—An anti-freeze solution can be used as the transfer fluid, but a heat exchanger would be necessary between the anti-freeze and the potable water with a concurrent loss in efficiency.

d. Solar Space Heating. The solar space heating system diagrammed in Figure 3.2.2 uses water as both the transfer and storage media.

When the collector temperature is higher than the storage tank temperature, a pump is activated which circulates water from the storage tank, through the collectors and returns to the storage tank. As a heating load occurs, air is blown from the space through heating coils which are supplied with solar-heated water. The air then is blown through existing coils (used as back-up) which are supplied with water from the secondary heating loop. Heat to these coils would be controlled by a two-stage thermostat.

An alternative to this interface would be to use solar to preheat the secondary heating loop. This would mean converting the loop from the present variable volume system to a variable temperature system.

The storage tank in this system is unpressurized and water simply drains from the collectors into the tank when the pump is off.

An alternate transfer fluid could be used which would allow the use of aluminum or steel collectors, but would mean an additional heat exchanger and a concurrent loss in efficiency.

e. Combination Solar Space and Hot Water Heating. The combination space and hot water heating system diagrammed in Figure 3.2.3 uses water as both the transfer and storage media in an unpressurized system.

The collection loop operates exactly as in the space heating system. However, distribution is divided between space and water heating. As a space heating load occurs, air is blown through a heating coil which is supplied with solar-heated water. The air passes through an existing coil, which serves as the back-up and is supplied with water from the secondary heating loop. As a domestic hot water load occurs, potable water flows through two heat exchangers. The first is supplied with solar-heated water from the storage tank. The second is the existing heat exchanger which serves as the back-up and is supplied with water from the primary heating loop.

f. Computer Simulation. Solar performance calculations were performed using a design program (FCHART) developed by the University of Wisconsin. FCHART is an interactive computer program used to calculate the thermal performance of solar space heating and domestic hot water heating systems. A general design procedure was developed at the University of Wisconsin from information gained from a simulation model capable of estimating the long-term thermal performance of solar heating systems to the system design parameters, heating loads and weather.

Solar and weather data for all calculations were taken from a draft copy of the California Solar Data Manual, January 1977, by the Energy and Environment Division of the Lawrence Berkeley Laboratory. Solar data are from the Richmond Field Station and weather data from the San Francisco International Airport.

When used with costs and economic data, the program performs a life-cycle cost analysis which compares the costs of the solar-assisted system with the costs of a conventional system on a present value basis. The difference between the two alternatives is the life-cycle value of the solar system (+ savings, - costs) in today's dollars.

Inputs into the economic analysis include: period of economic analysis; annual interest rate on mortgage; term of mortgage; annual market discount rate; present cost of auxiliary fuel; fuel cost increase; constant solar costs; collector area dependent costs; first year insurance and maintenance expenses; and annual increase in insurance and maintenance expenses.

The program also calculates property taxes and income tax deductions for interest payments, but since the airport pays no taxes, these were neglected.

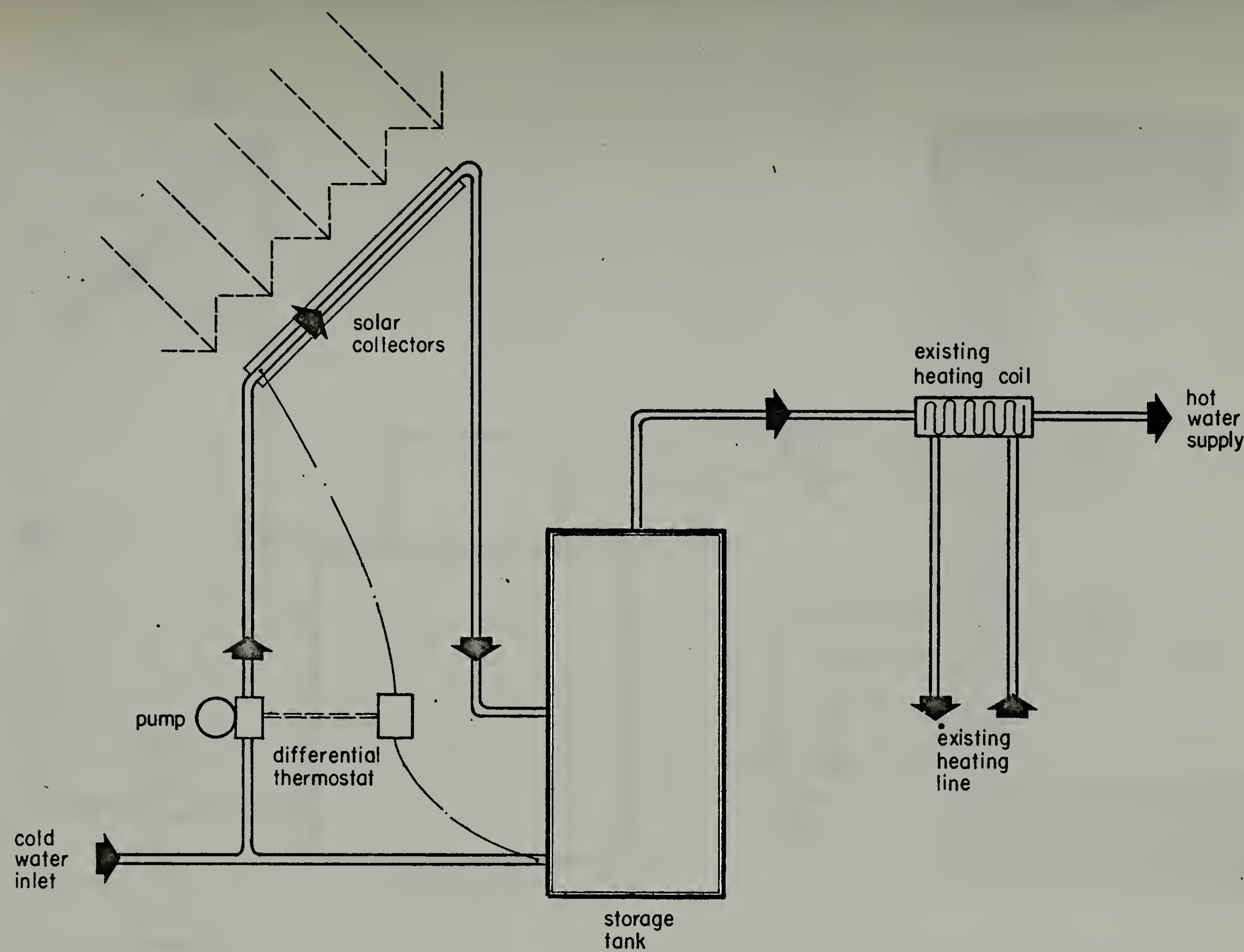


fig. 3.2.1 typical domestic hot water solar heating system

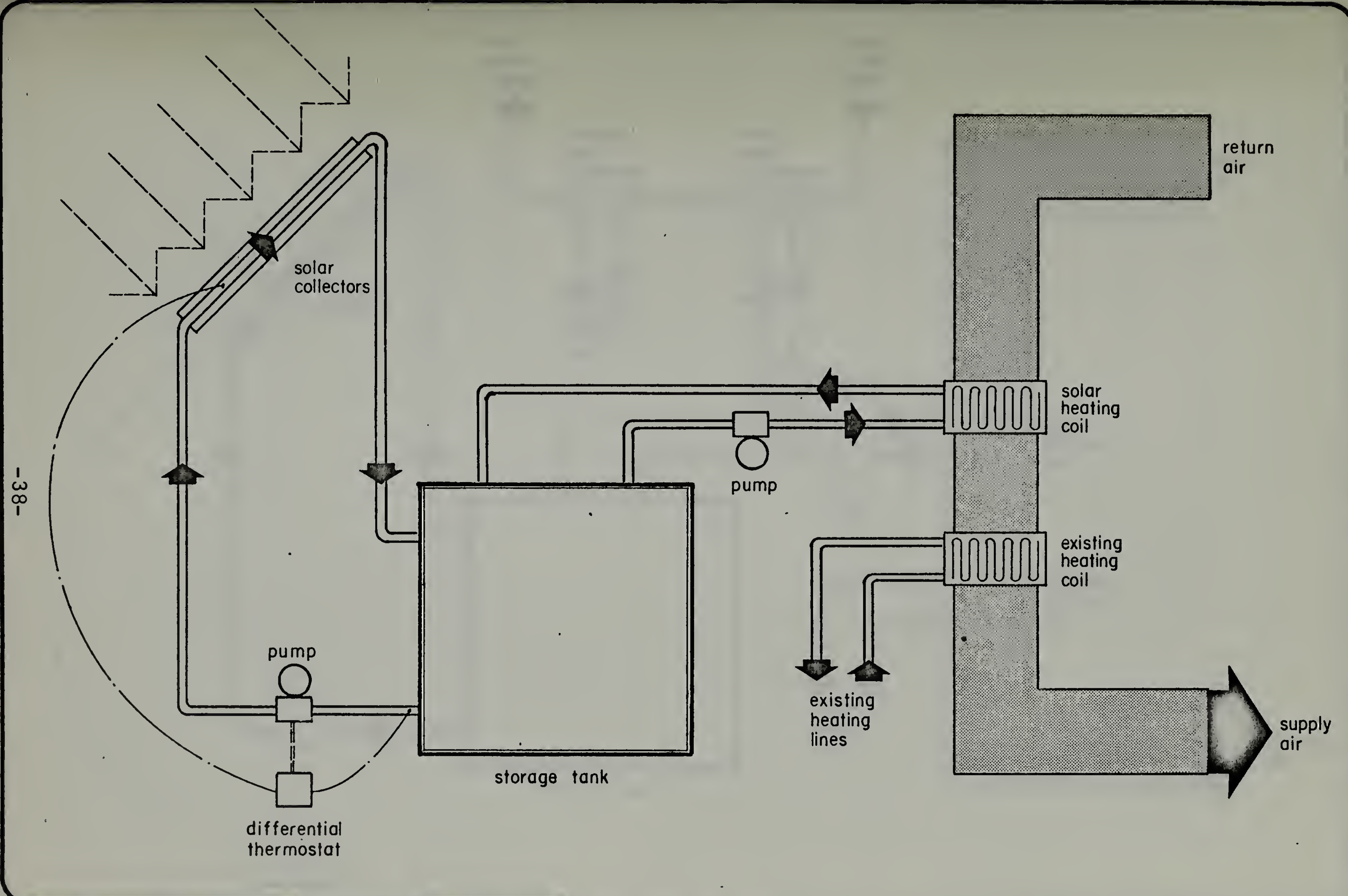


fig. 3.2.2 typical solar space heating system

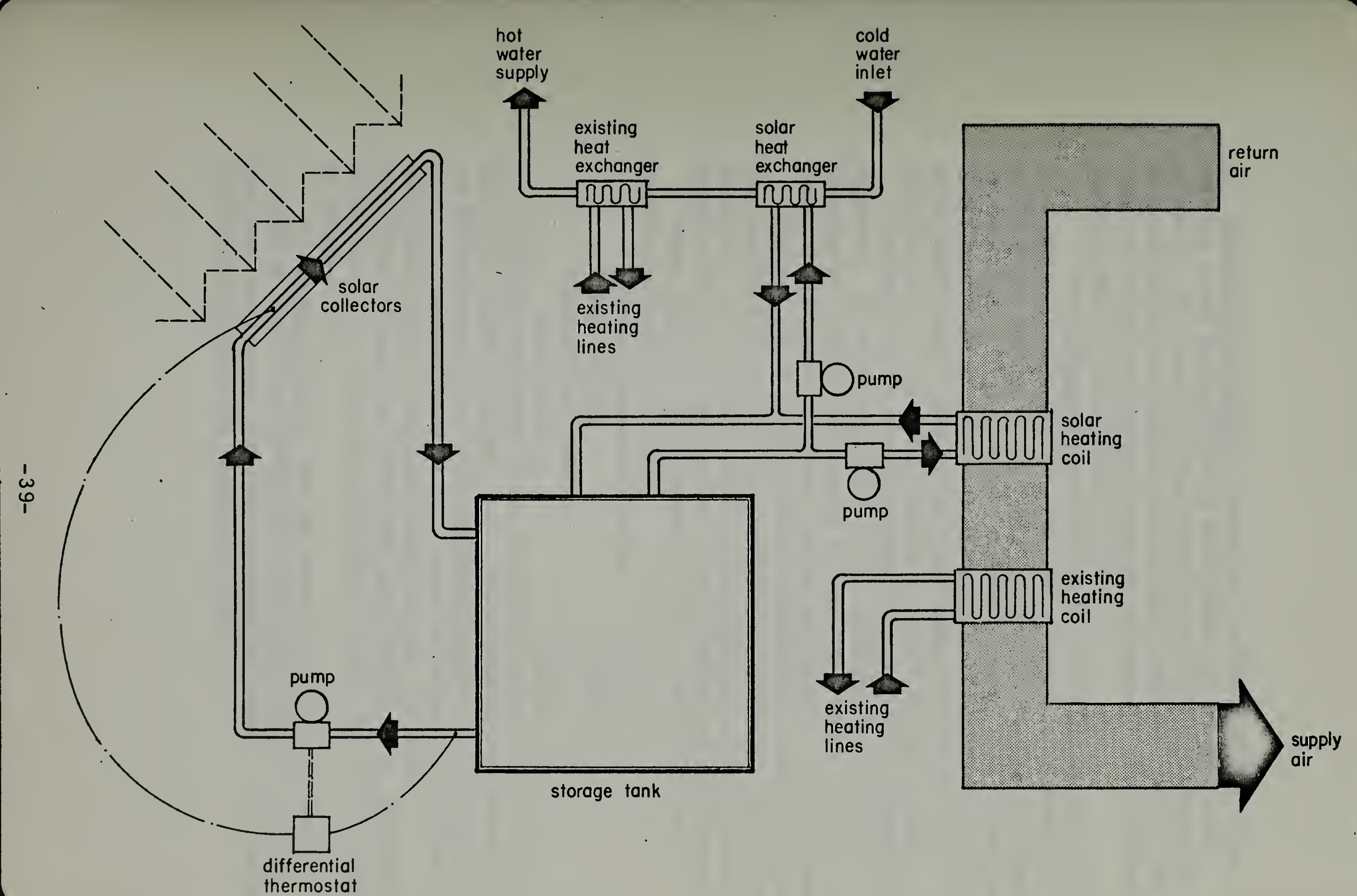


fig. 3.2.3 typical solar space and DHW heating system

g. Sensitivity Analysis. A sensitivity analysis of one system was run to aid the selection of base inputs to be used on all systems. This analysis also identifies the relative importance of the different parameters. Piers H and I were selected for the analysis because of their permanence in relation to the proposed modernization and replacement plan.

The collector tilt was varied for a given collector area. Test runs had shown that economically optimum sizes would be in the 20 per cent to 40 per cent range, so the tilt was optimized for that size. Larger systems, supplying greater than 50 per cent of the load, will optimize with steeper tilts. This is because when solar contribution is only a small percentage of the load, it is utilized over the full year, yielding a shallow collector angle.

The effect of tilt on performance is not as much as might be expected. As shown in Figure 3.2.4, adjusting the tilt by 20° changes the system performance by less than two per cent for domestic hot water, and less than one per cent for the other systems.

System cost is divided between fixed costs (costs which are not dependent on system size, such as the interface with back-up systems), and collector-dependent costs (those which are proportional to the size of the system, such as collectors and storage).

Fixed costs for each system will vary. For Piers H and I, they are estimated as:

Domestic hot water heating	\$ 3,000
Space heating	86,800
Domestic hot water and space heating	\$89,800

Collector-dependent costs are graphed against the 20-year life-cycle value in Figure 3.2.5. (Solar systems are commonly built for \$20 per square foot in the residential market, but on a large commercial project such as this, costs will climb much higher.) Estimated collector-dependent costs are given in Table
They show a range from \$33 to \$49 per square foot. A base input of \$40 per square foot was selected as represented by the circle in Figure 3.2.5.

Gas price increases were estimated at a rate which rose sharply at first, then leveled off. With the help of a computer, this rate was recalculated into an equivalent annual rate of increase. The same procedure was performed for oil.

Table 3.2.1

Estimated Costs as a Function of Collector Area

(excluding fixed costs of interface)

	Dollars per Square Foot of Collector	
	Minimum	Maximum
Collector	$12.00	$14.00
Storage	2.00	4.00
Transfer loop	3.00	5.00
Subtotal	$17.00	$23.00
Subcontractor overhead (15-20%)	2.55	4.60
Subtotal	$19.55	$27.60
Subcontractor profit (10-15%)	1.95	4.14
Subtotal	$21.50	$31.74
General contractor overhead and profit (15%)	3.22	4.76
Subtotal	$24.72	$36.50
Bond (1%)	.25	.36
Total construction cost	$24.97	$36.86
Net capitalized interest during construction	.04	.04
Professional services (12.5%)	3.12	4.60
Subtotal	$28.13	$41.50
Cost escalation (12% per year, one year)	3.37	4.98
Subtotal	$31.50	$46.48
Contingency (5%)	1.57	2.32
Total	$33.07	$48.80

In 1976 the airport operated on a 90 per cent gas/oil ratio, but P G and E will not be able to supply this same amount in the future and has allocated the amounts given in Table 3.2.2. The exact ratio will depend primarily on the availability of the cheaper gas.

For estimating purposes, a 50/50 gas/oil ratio was assumed. The initial cost of gas is 30 cents per therm (delivered) and 40 cents per therm for oil, yielding a 35 cents per therm average. The equivalent annual increase in fuel price for gas was estimated at 17 per cent per year, and 15 per cent per year for oil, yielding a 16 per cent average. This was used as the base input as represented by the circle in Figure 3.2.6.

Yearly maintenance costs including equipment repairs, replacement and insurance. One area of particular concern is the effect of airplane exhausts on the cost of maintenance required to keep the collector glazing clean. From those with whom we discussed this problem, the consensus of opinion was that the majority of fall-out at the airport occurs at the end of the runways and not over the terminals. An investigation of existing skylights and their cleaning requirements showed that most are cleaned on an irregular and infrequent basis. The large dome skylights in the International Rotunda are cleaned every six weeks. It seems that no accumulation of dirt requires special solvents or cleaners to remove.

It has been found under most conditions that solar collectors do not require cleaning other than that provided naturally by rainfall. Some manufacturers recommend annual or semi-annual cleaning of the cover sheets. Therefore, we concluded that normal rainfall and perhaps an occasional washing will adequately keep the collectors clean at the airport.

Yearly maintenance costs, including insurance, are given as a percentage of the initial cost. As the size and initial cost of a system increase, this percentage should drop. A base input of two per cent was used as represented by the circle in Figure This is estimated as the percentage necessary for a relatively small system, in the range of 20 to 40 per cent solar.

The value of money refers to the interest rate paid on money borrowed to finance the solar system.

Table 3.2.2

Projected Natural Gas Allotment*

for San Francisco International Airport

(As a Percentage of 1976)

Month	1977-78	1978-79
October	100	98
November	82	72
December	30	15
January	11	4
February	53	32
March	76	61
April	88	81
May	100	99+
June	100	100
July	100	100
August	100	100
September	100	100

*from P G and E, San Mateo

Term of economic analysis. Solar systems are long-term investments requiring large capital costs which realize future savings. A 20-year analysis is the accepted norm, based on the life of conventional mechanical systems. The time was extended to 30 years to see the effects on a longer-lasting system. A 20-year analysis was used as the base input as represented by the circle in Figure 3.2.9.

Comparison. The graphs of the sensitivity analysis show the relative influence of these parameters. Fuel price escalation and value of money are at the mercy of politics and international economics, and there is nothing that can be done to influence them. Something can be done, however, about the initial cost of the system, maintenance costs and the term of economic analysis. The graphs show the overwhelming influence of time on the economic value of the system. Higher initial costs have a relatively small impact on the long-term value. This suggests that extra initial costs which add to the life of the system could be well spent. Also, a system that can survive the inevitable remodeling that airports experience would realize much greater returns.

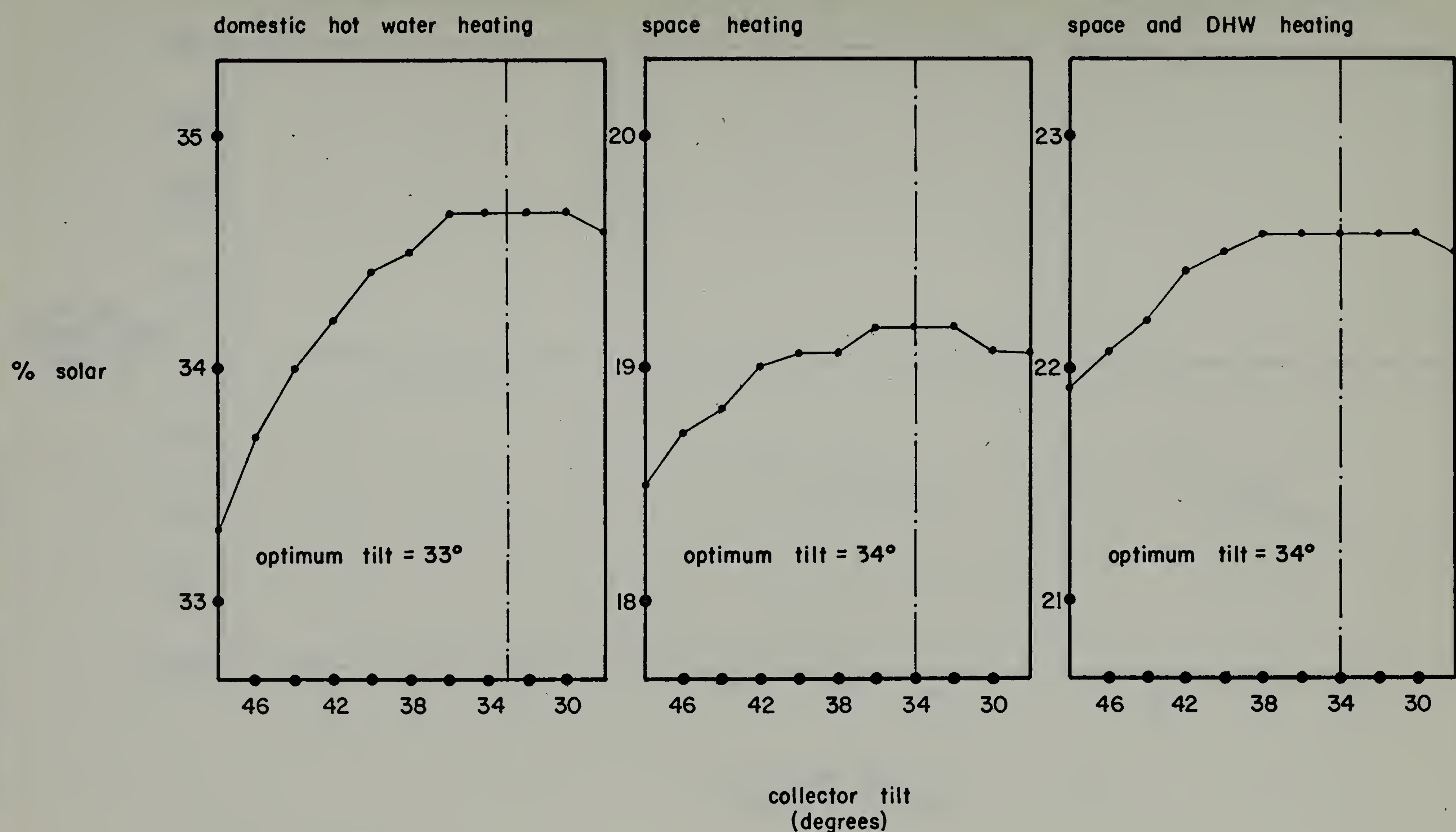
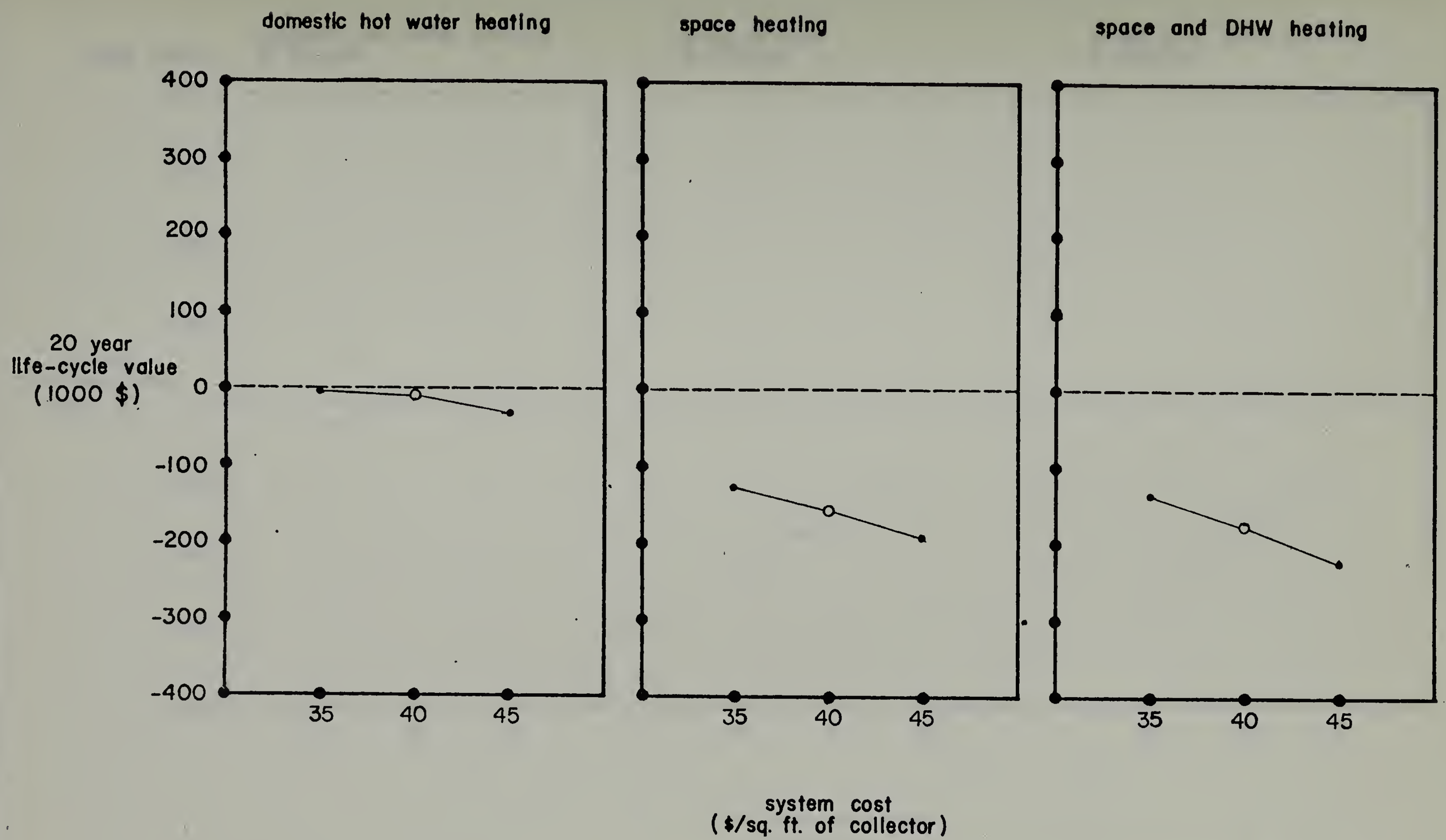


fig. 3.2.4 sensitivity analysis: piers H & I

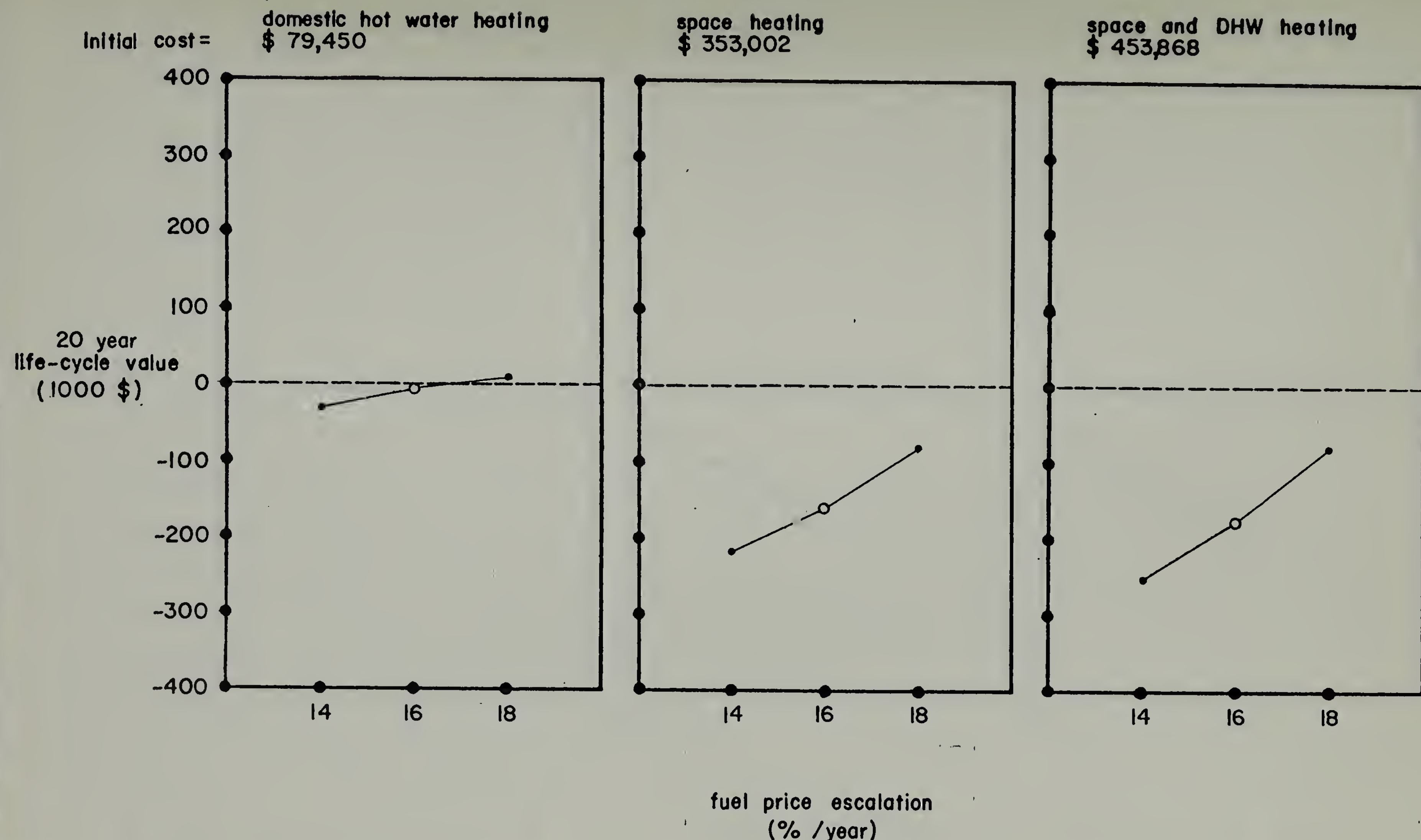


san francisco international airport

solar feasibility study

fig. 3.2.5

sensitivity analysis: piers H and I



san francisco international airport

solar feasibility study

fig. 3.2.6

sensitivity analysis: piers H and I

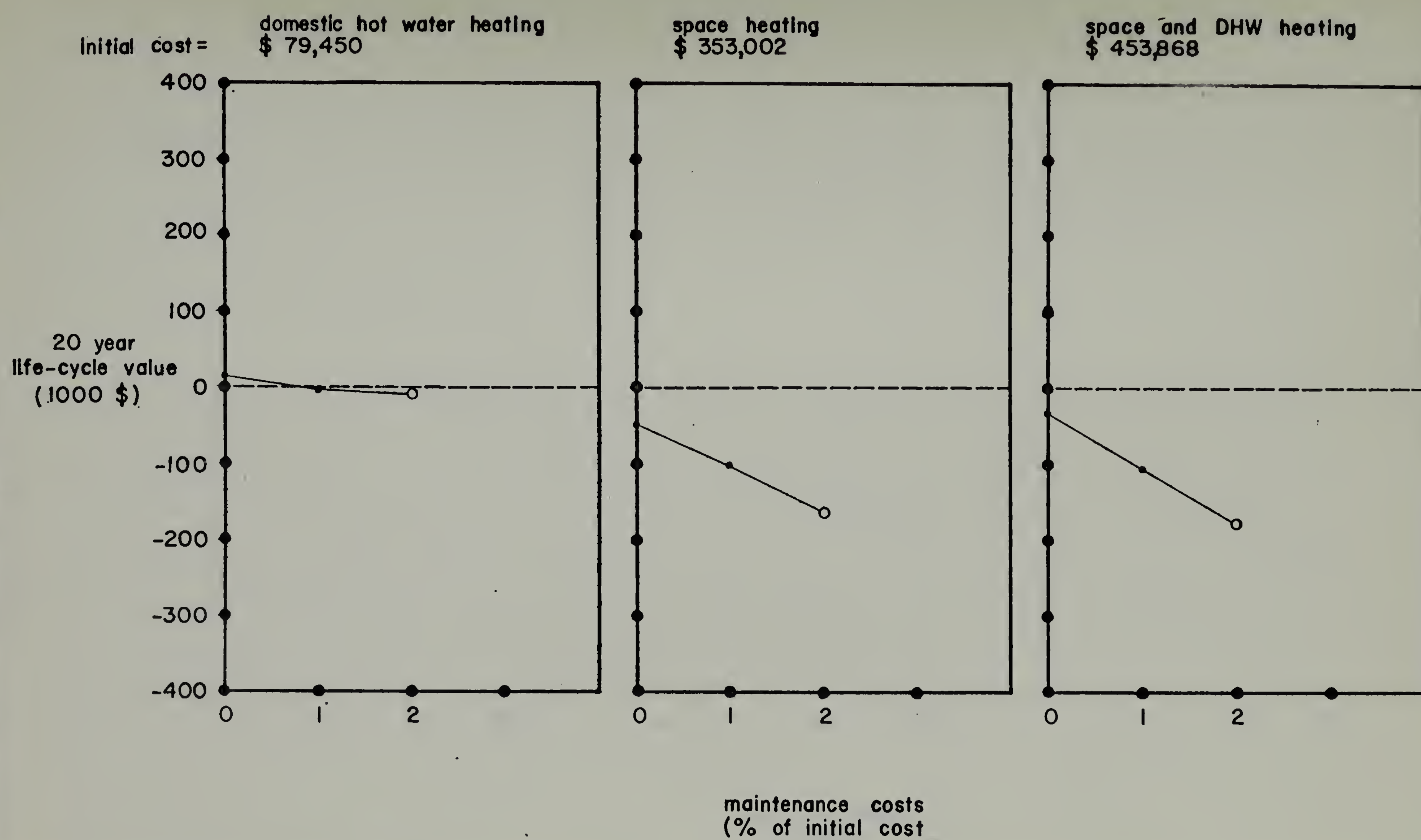


fig. 3.2.7

sensitivity analysis: piers H and I

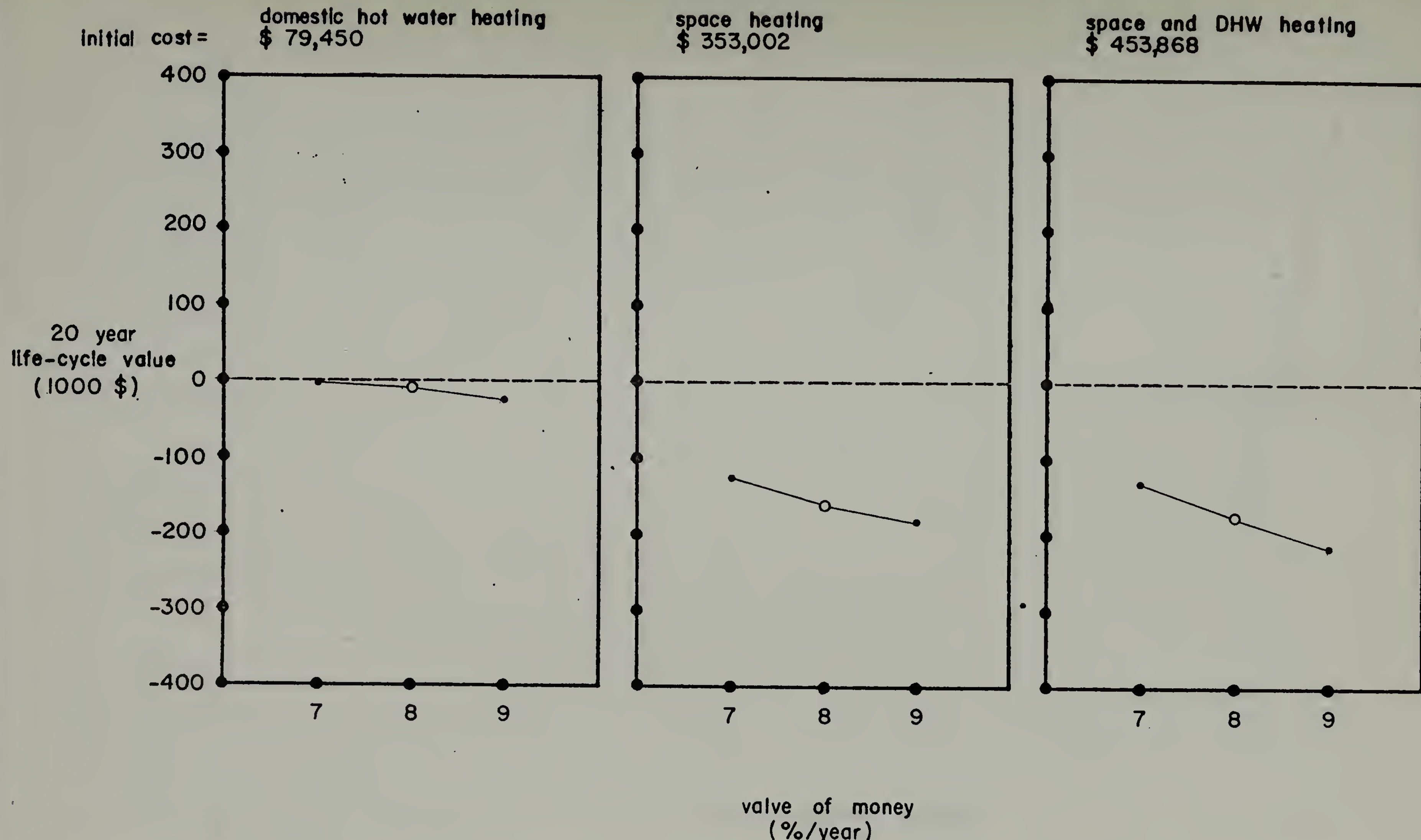
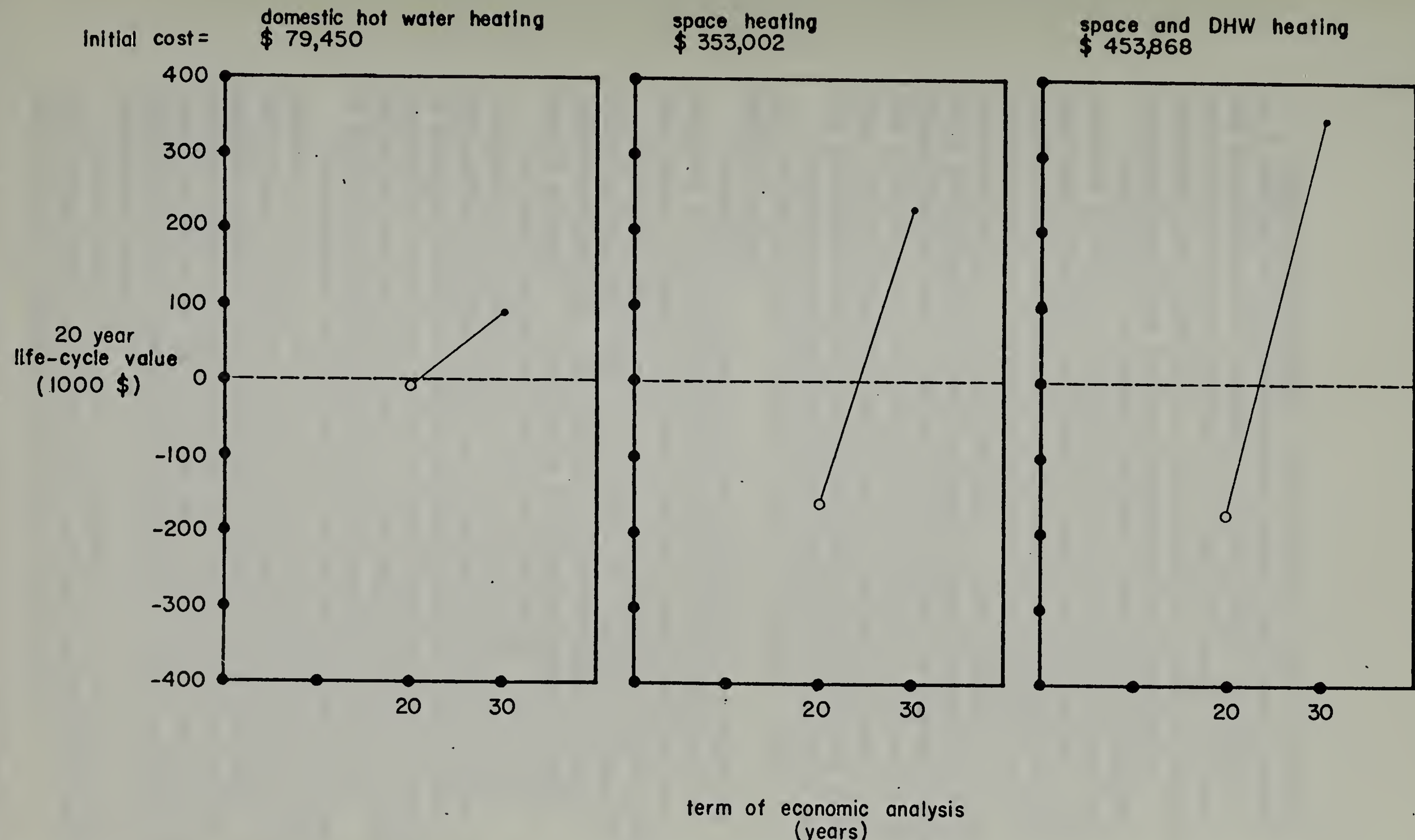


fig. 3.2.8 sensitivity analysis: piers H and I



san francisco international airport

solar feasibility study

fig. 3.2.9

sensitivity analysis: piers H and I

h. System Optimization. The following analyses are based on a particular set of assumptions about the future. Although the assumptions are intended to be reasonable, it would be presumptuous to assume that the future will match any preconceived set of estimates. The sensitivity analysis previously presented put these future assumptions into perspective.

The FCHART computer simulation, previously described, provides a method for determining the economically optimum solar space heating and domestic water heating system. The system size is optimized by minimizing the life-cycle cost of the solar system. System sizes are selected in pairs for analysis using a searching technique. The optimum is attained when the difference in the two areas under consideration is 32 square feet or less. For each system size, the thermal analysis and economic data are used to calculate the cash flow for each year, the resulting life-cycle cost for the solar system, and the life-cycle cost for the conventional system without solar.

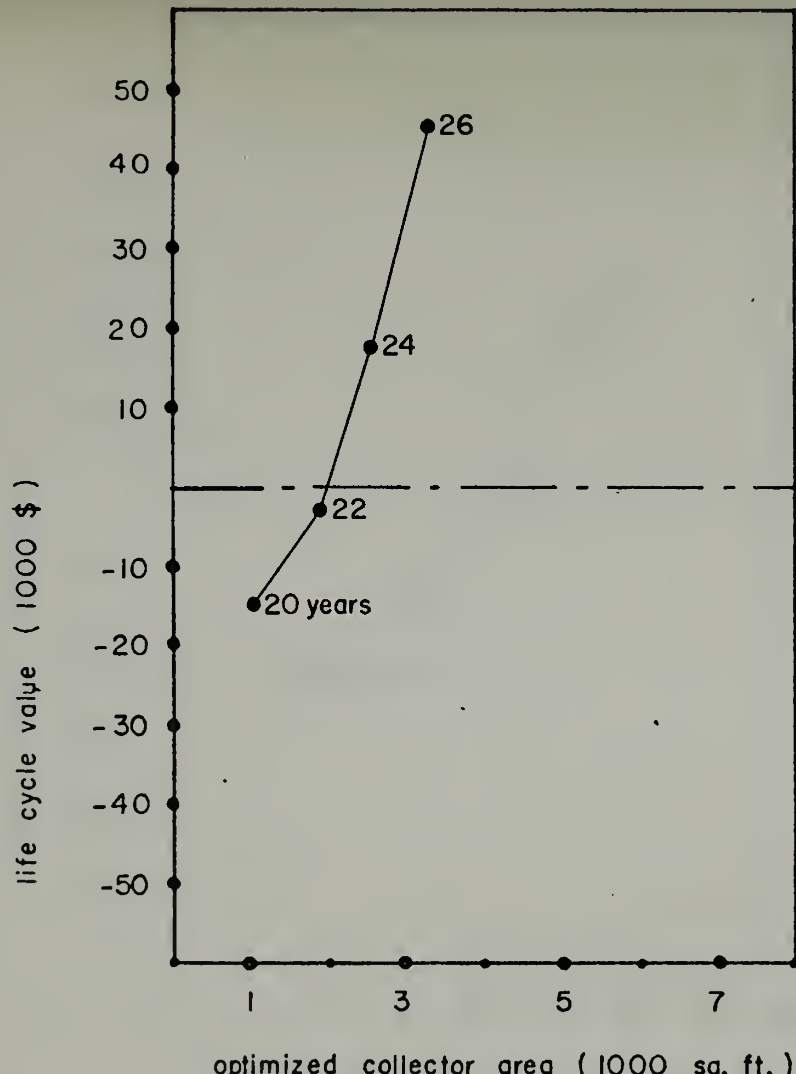
The difference between these two life-cycle costs is the life-cycle value of the solar system (+ savings, - costs) in today's dollars.

The airport complex has been divided into ten zones for separate analysis. Three systems have been optimized for each zone: domestic hot water heating; space heating; and a combination space and hot water heating system. The optimum collector area was determined for 20, 22, 24 and 26 years of economic analysis. The optimum collector differs for each term of analysis. Longer terms yield larger optimum areas.

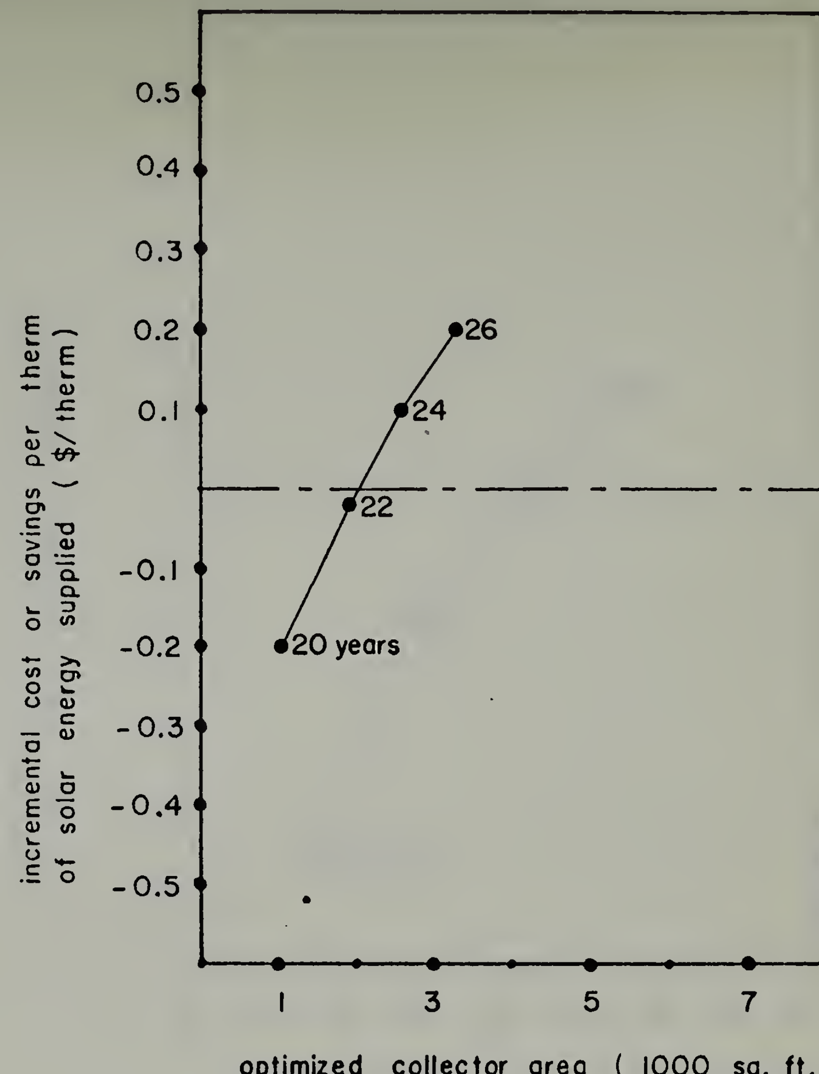
For each system two graphs are presented. One plots the optimized collector area against its life-cycle value. The plotted collector areas are optimized for different years of economic analysis. The necessary time the system must operate to become economically self-supporting and the optimum collector area for that system can be determined from the point at which the plotted line crosses the zero life cycle value.

The decision to build solar is not always based on economic criteria. Energy savings can also be a significant factor. For this reason, a second graph is presented which directly corresponds to the first. In the second, however the optimized collector area is plotted against the incremental value of the energy supplied by the solar system. Minus (-) represents the additional cost of energy over conventional fuels, and plus (+) represents savings.

These graphs illustrate the importance not only of a system which itself will last a long time, but also one that will survive the inevitable remodeling that airports experience.

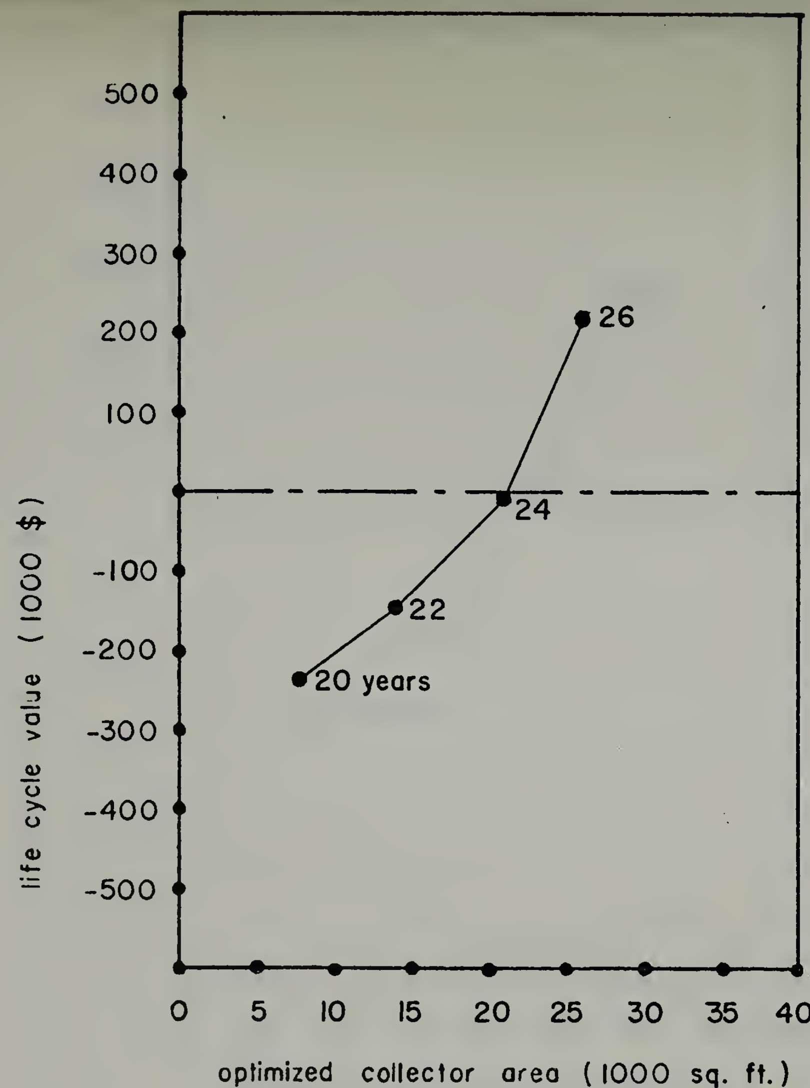


life cycle value vs. optimized collector area

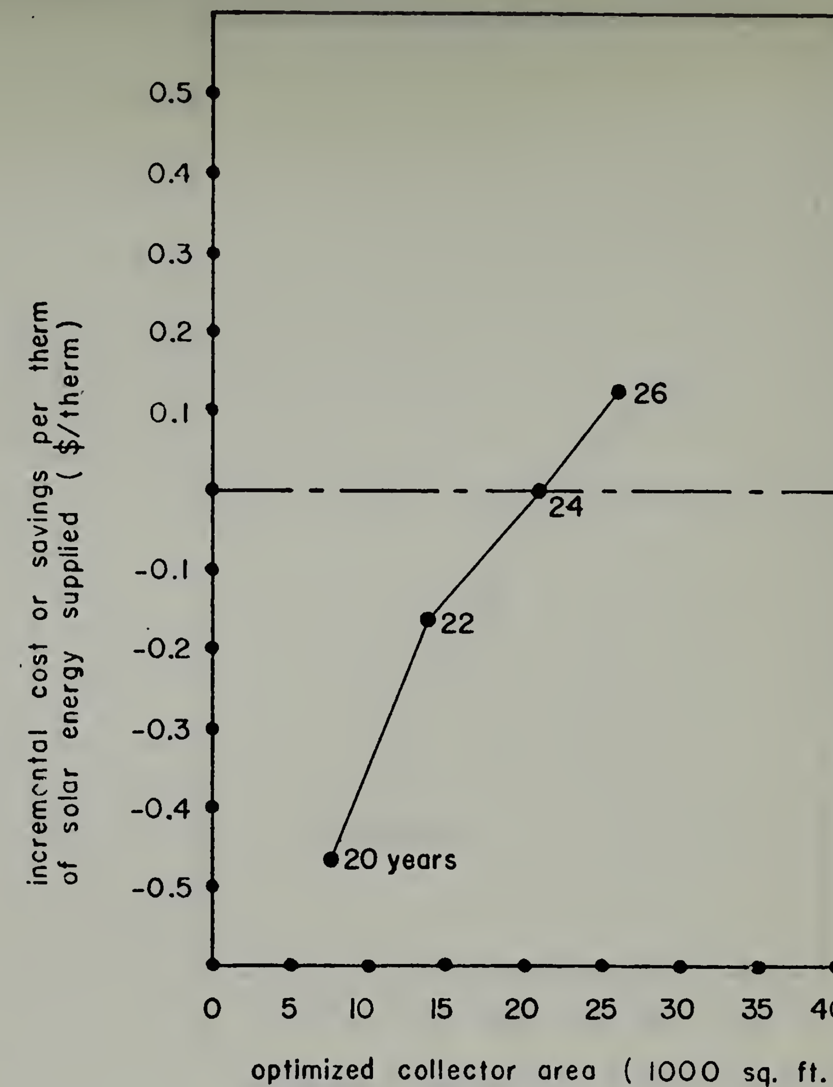


Incremental value of solar energy supplied vs. optimized collector area

fig. 3.2.10 DHW- south terminal (installed cost = $ 78,190)



life cycle value vs. optimized collector area



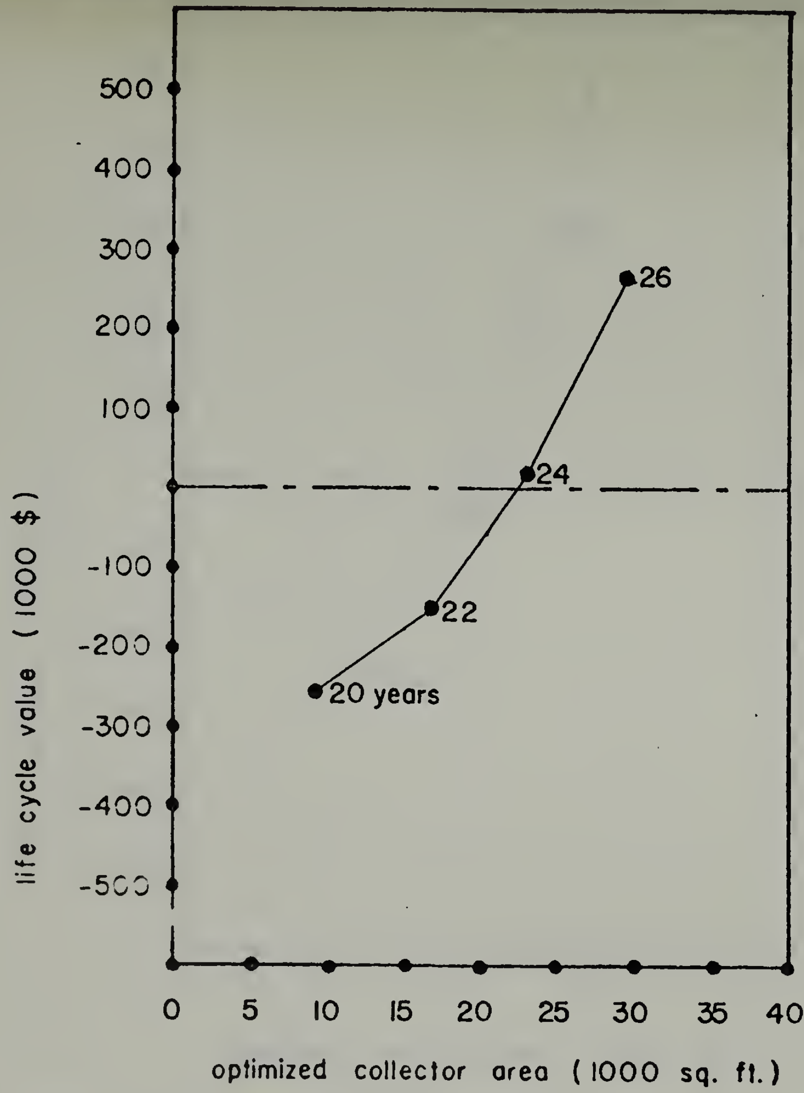
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport

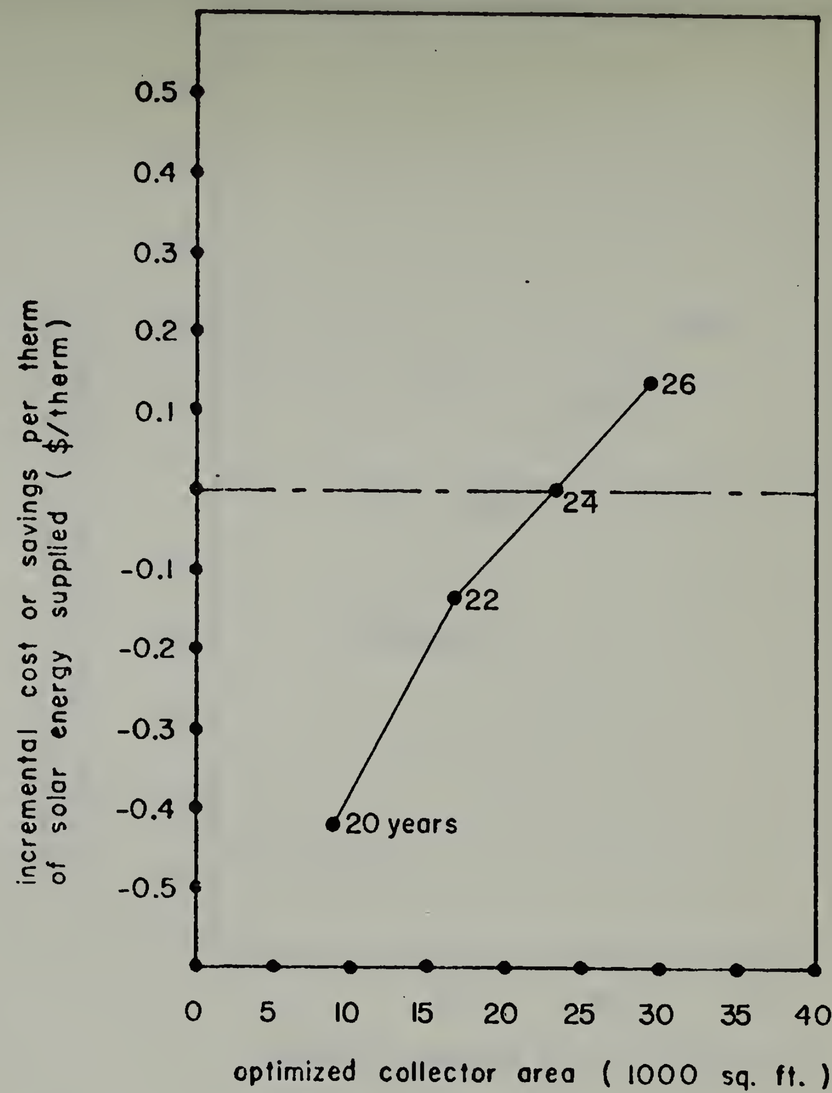
solar feasibility study

fig. 3.2.11

space- south terminal (installed cost = $ 942,750)



life cycle value vs. optimized collector area



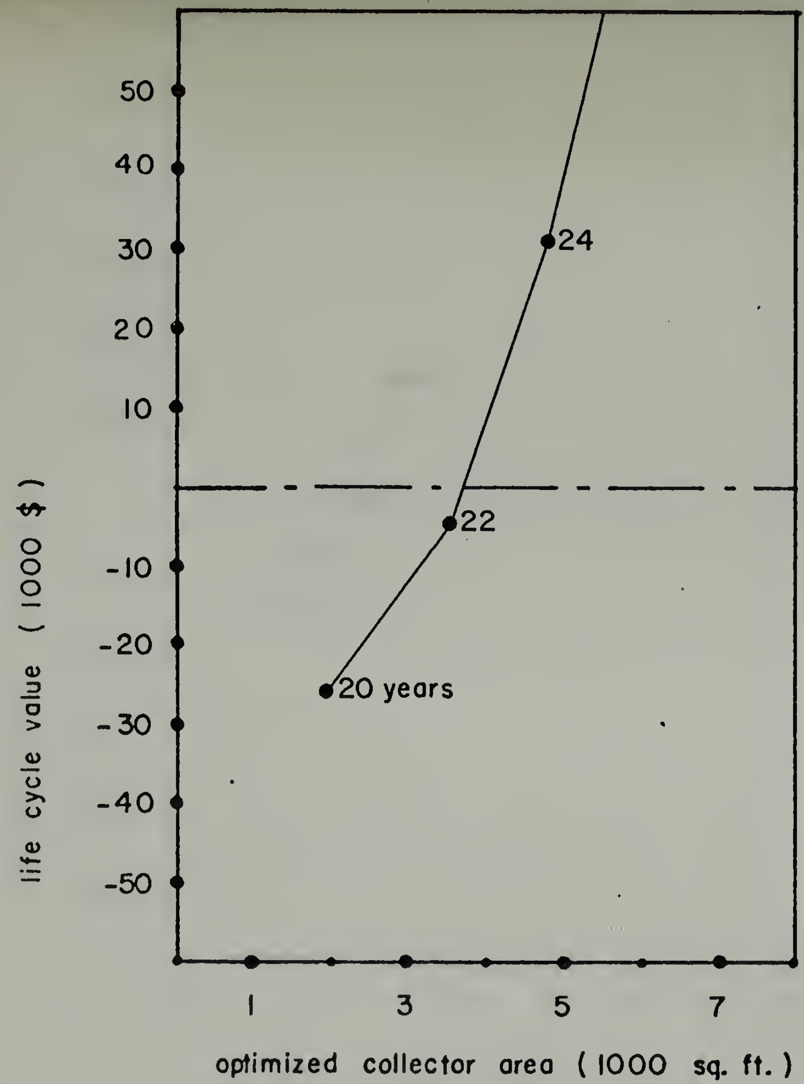
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport

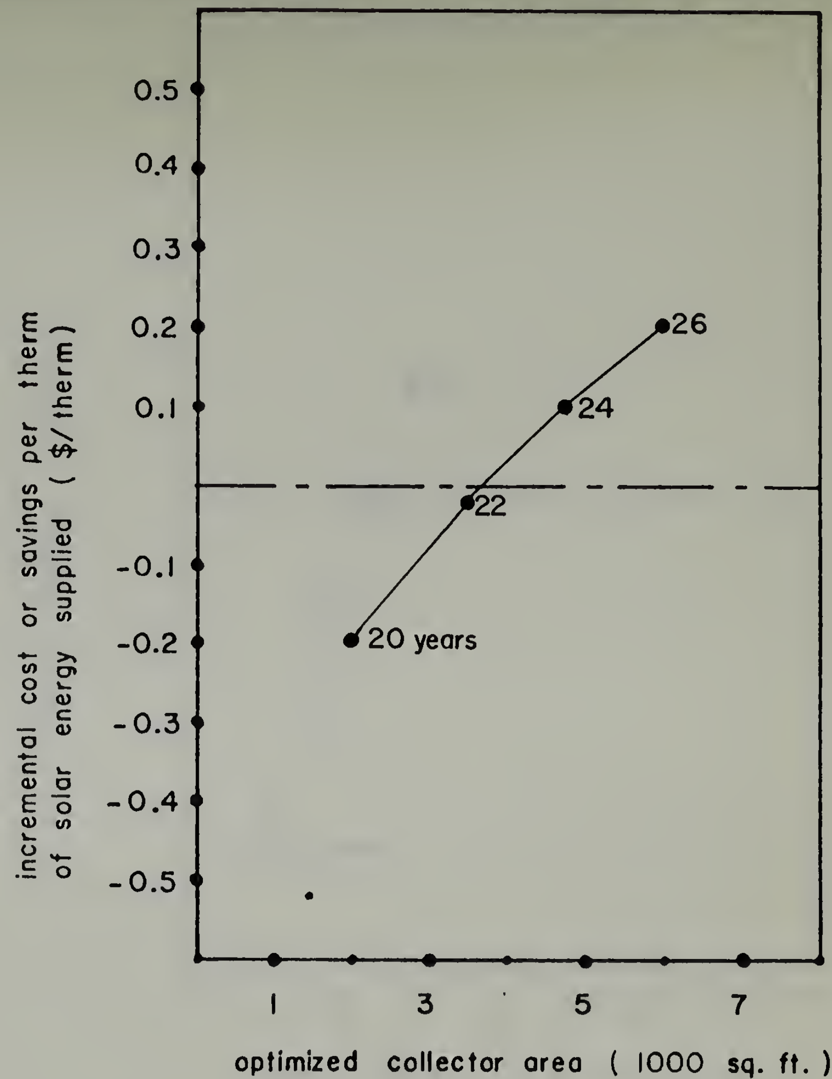
solar feasibility study

fig. 3.2.12

DHW & space- south terminal (installed cost = $ 1,078,470)

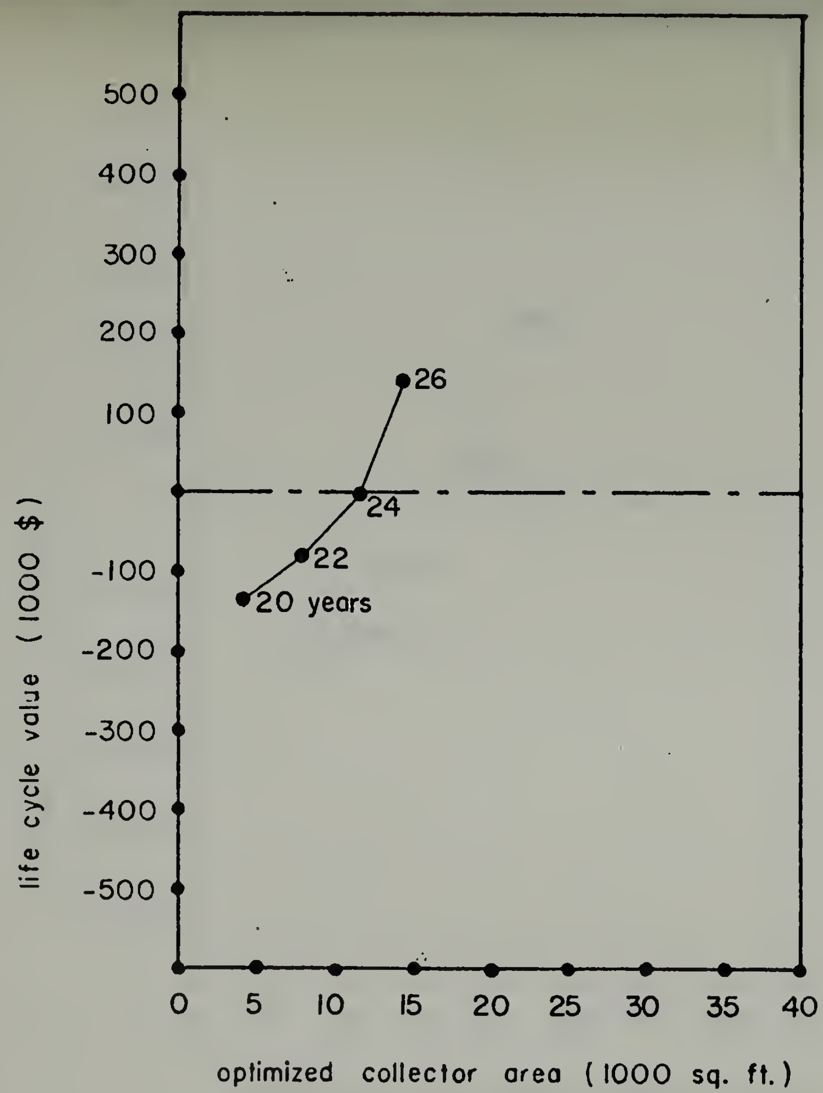


life cycle value vs. optimized collector area

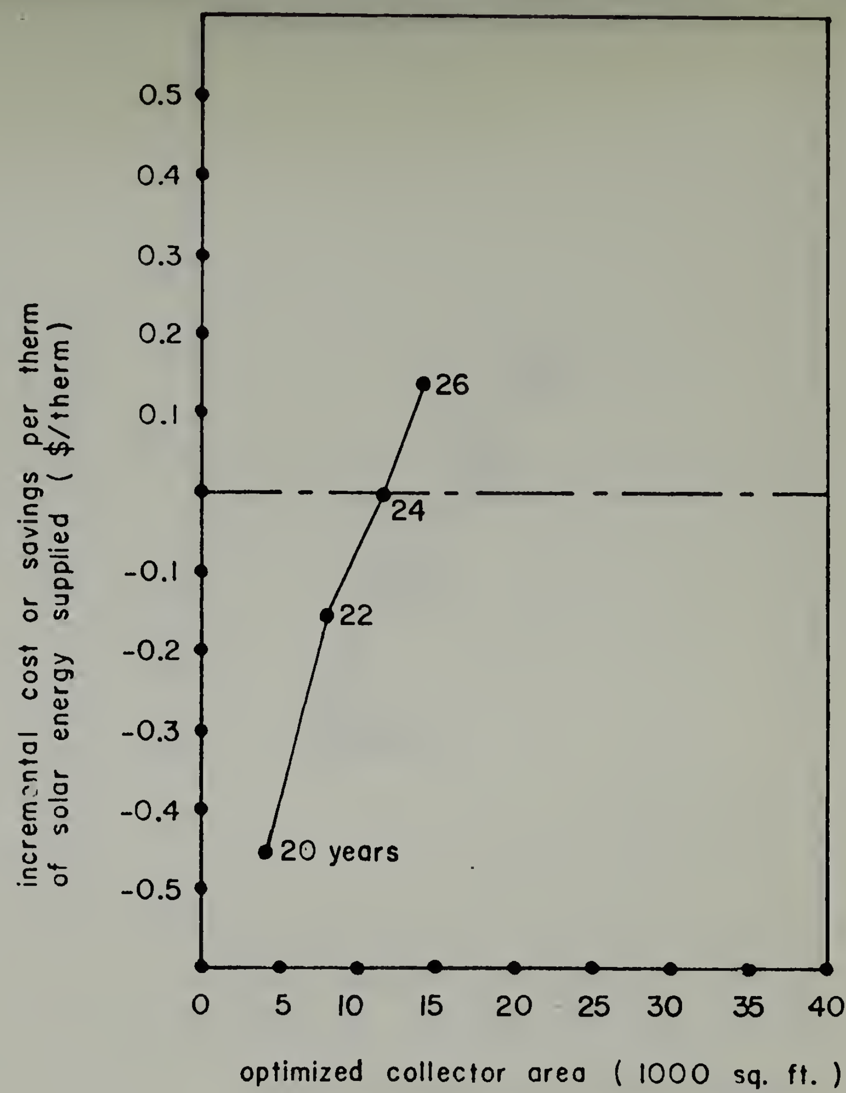


Incremental value of solar energy supplied vs. optimized collector area

fig. 3.2.13 DHW- central terminal (installed cost = $ 144,810)



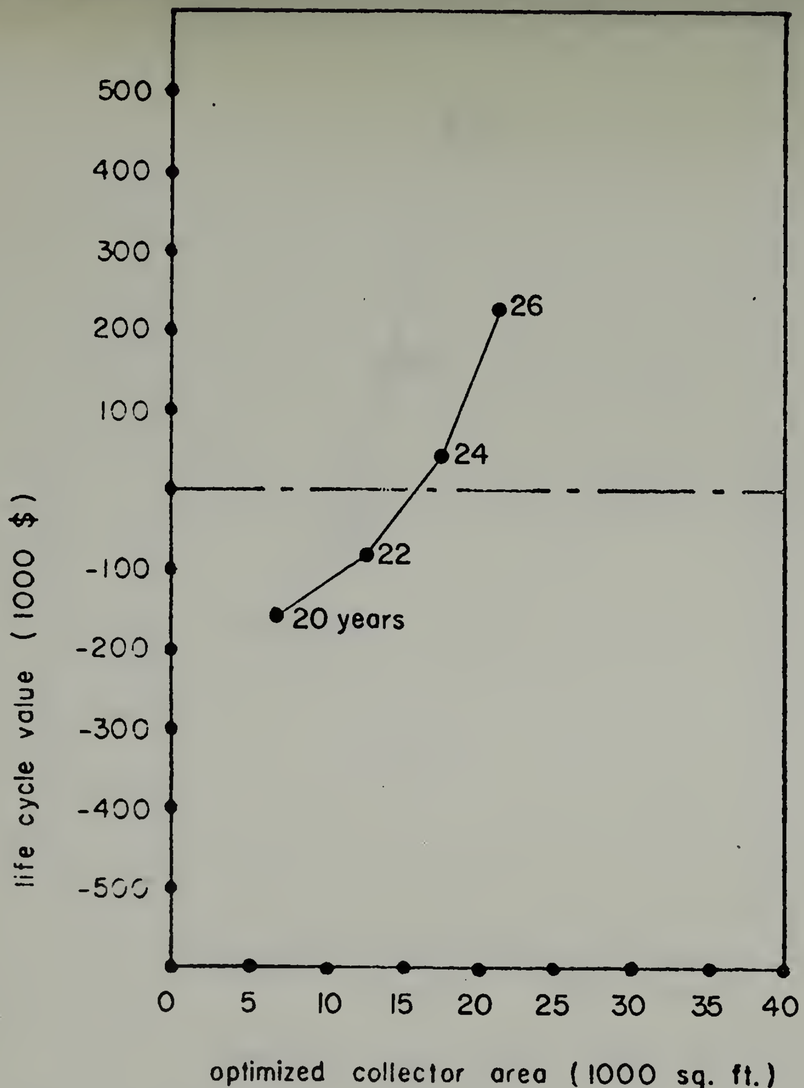
life cycle value vs. optimized collector area



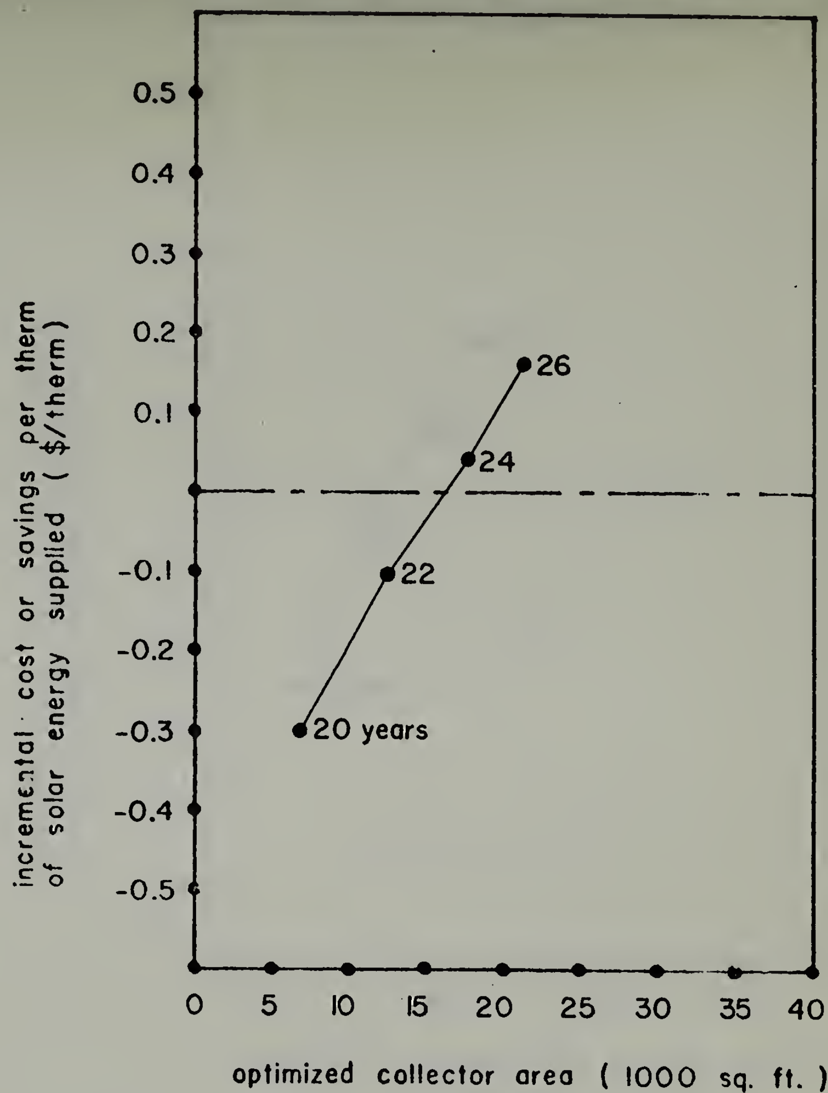
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport solar feasibility study

fig. 3.2.14 space- central terminal (installed cost = $ 523,370)

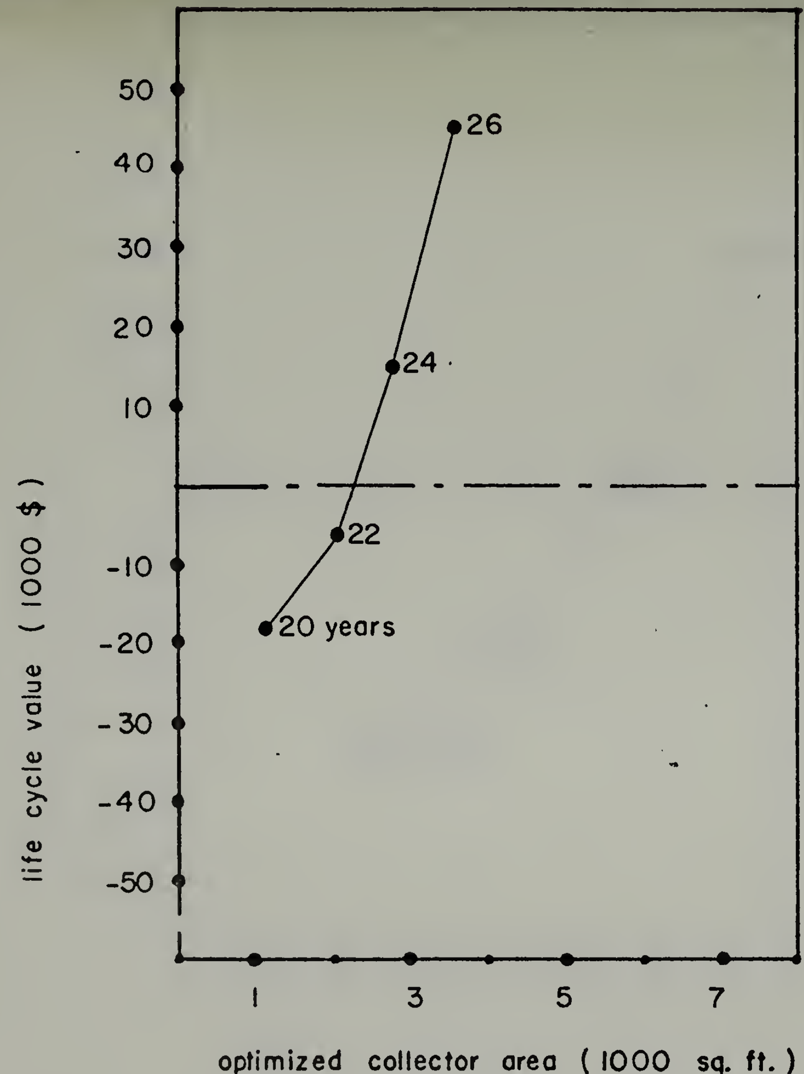


life cycle value vs. optimized collector area

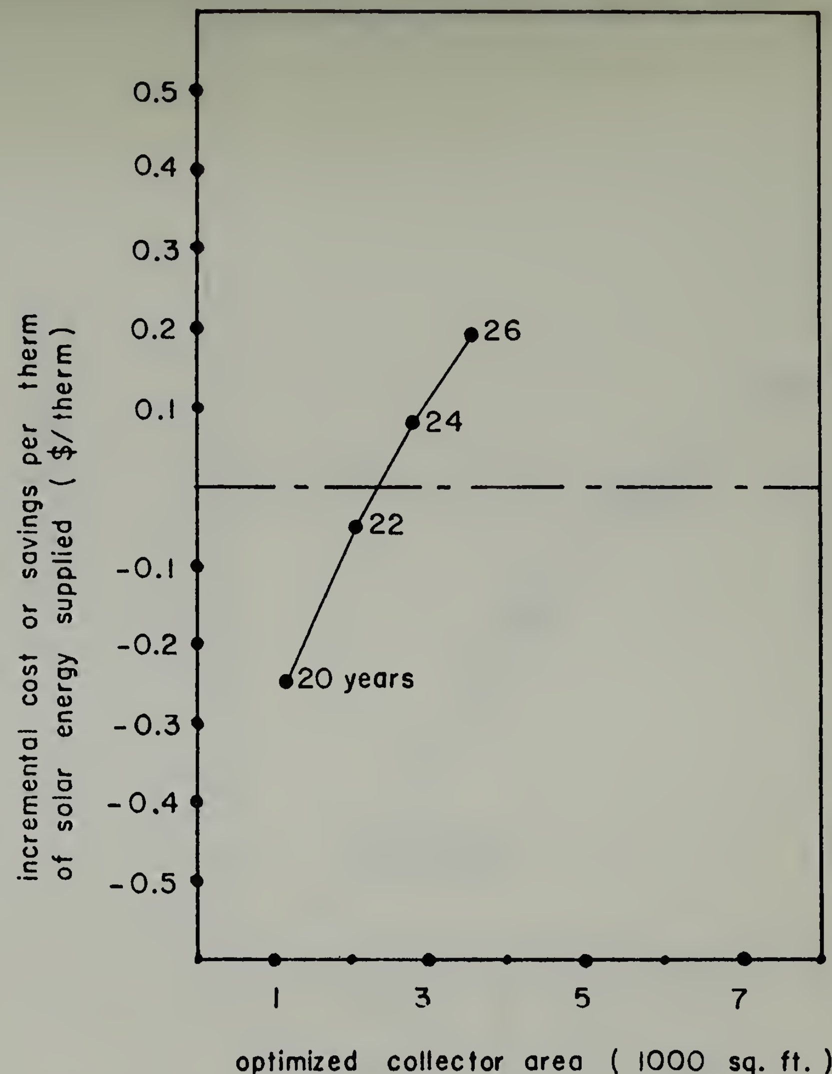


incremental value of solar energy supplied vs. optimized collector area

3.2.15 DHW & space-central terminal (installed cost = $ 760,370)

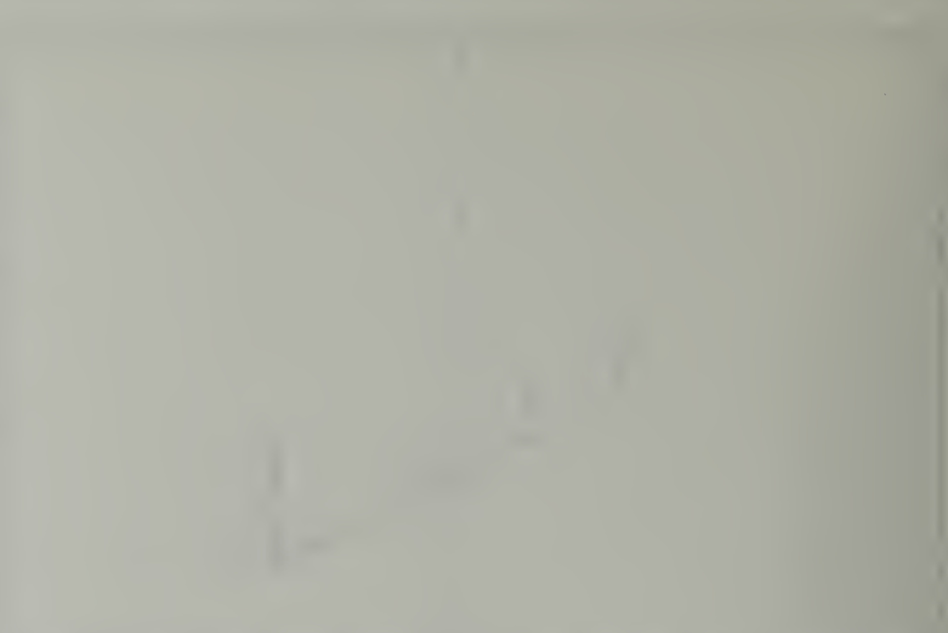


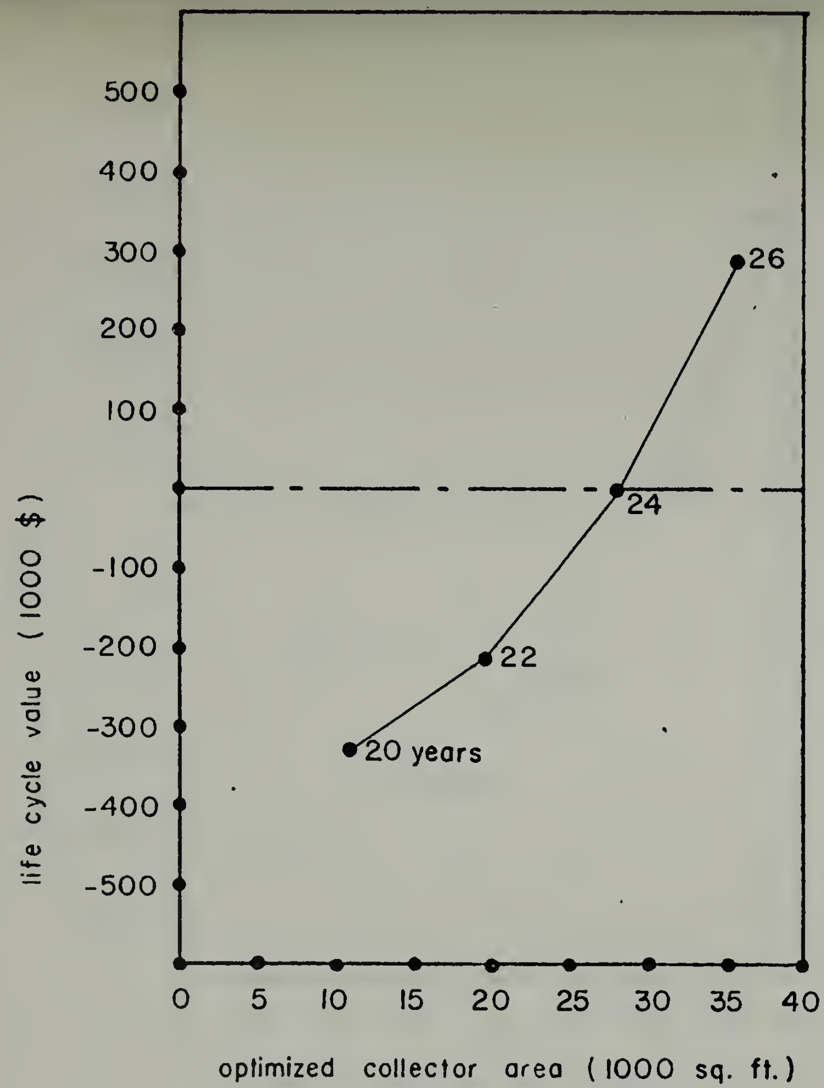
life cycle value vs. optimized collector area



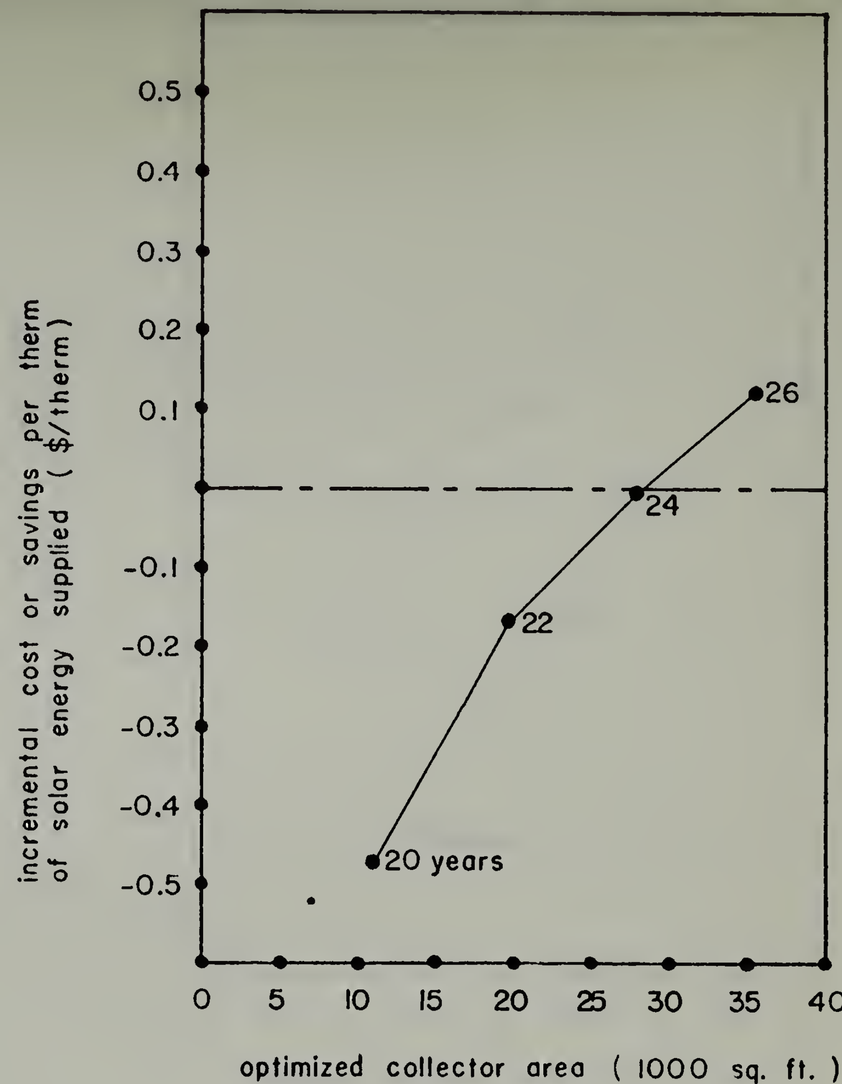
Incremental value of solar energy supplied vs. optimized collector area

fig. 3.2.16 DHW- north terminal (installed cost = $ 87,530)



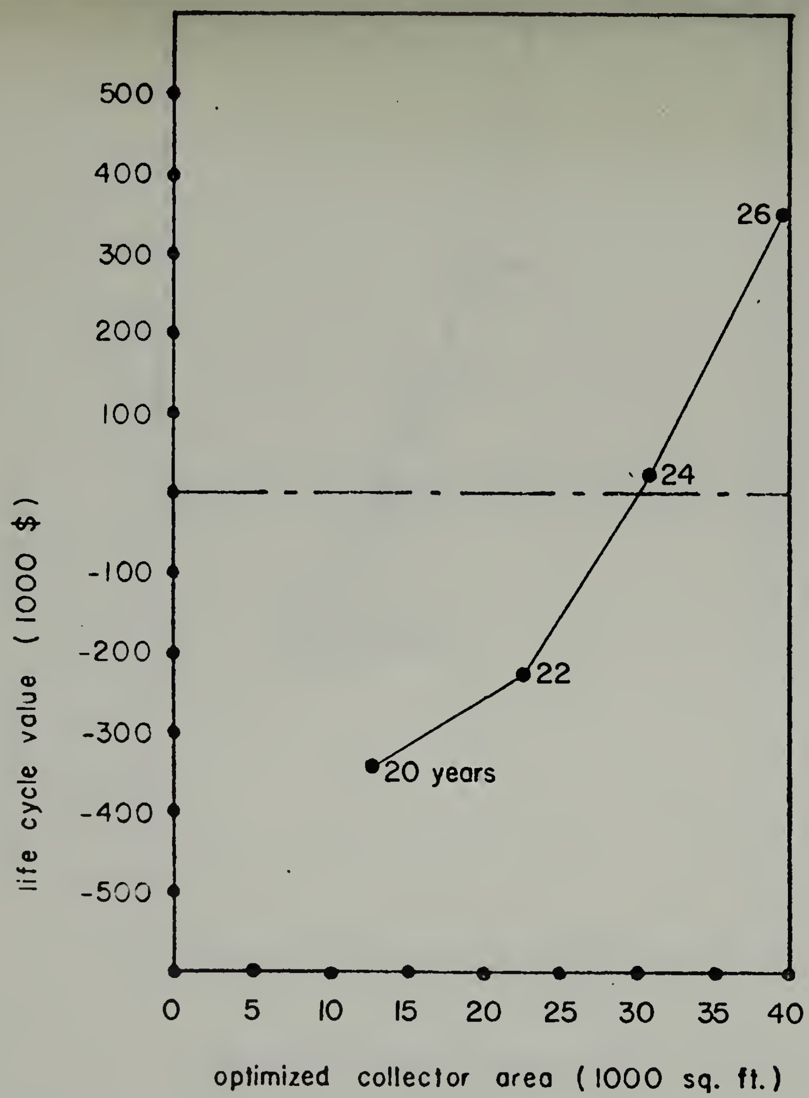


life cycle value vs. optimized collector area

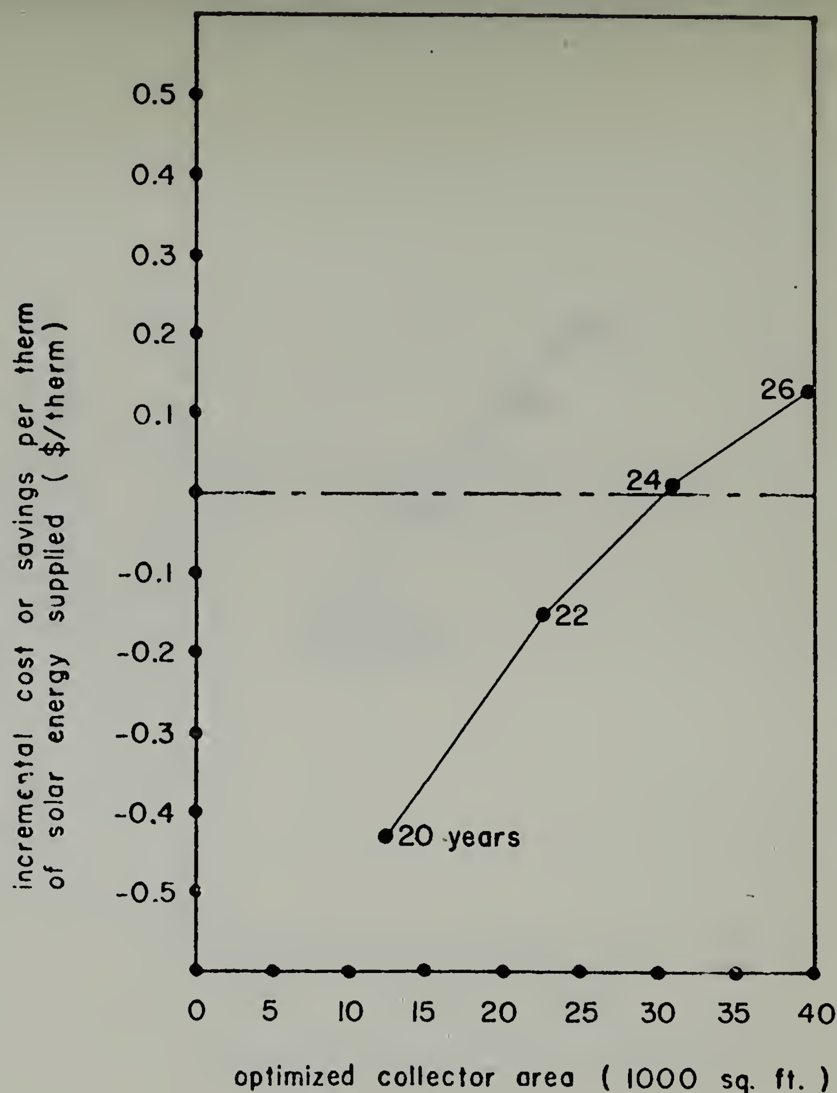


incremental value of solar energy supplied vs. optimized collector area

fig. 3.2.17 space- north terminal (installed cost = $ 1,296,670)

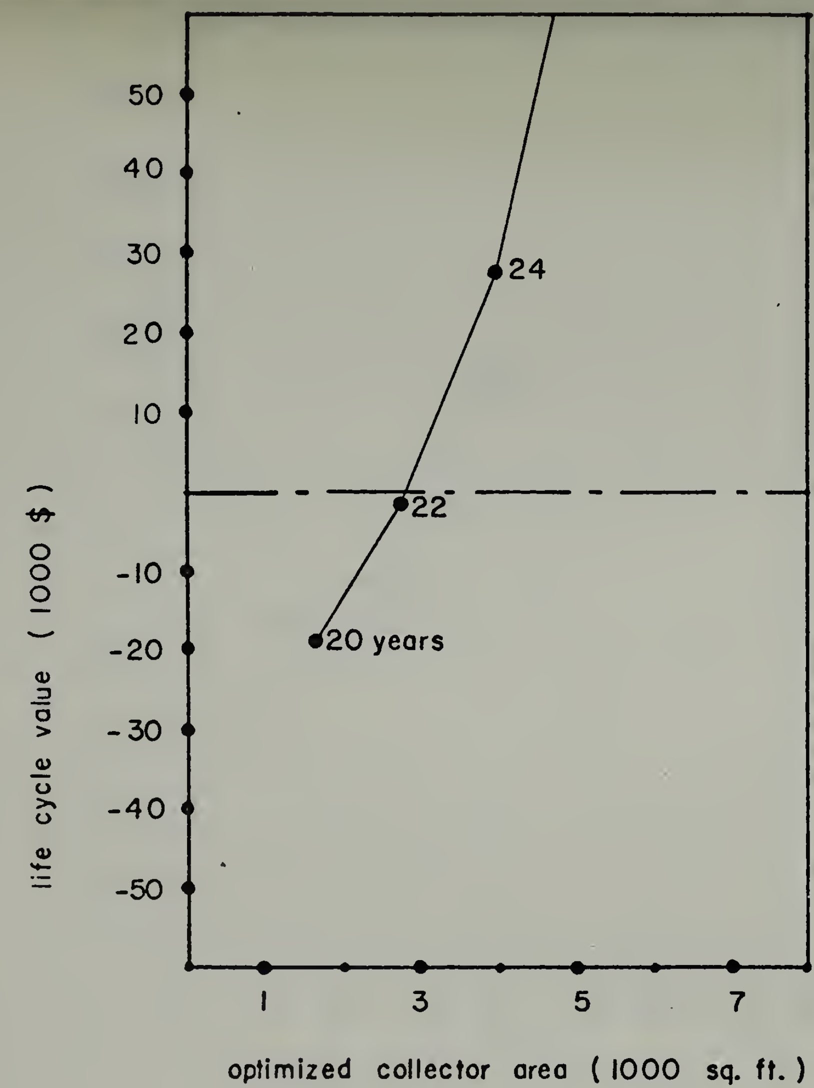


life cycle value vs. optimized collector area

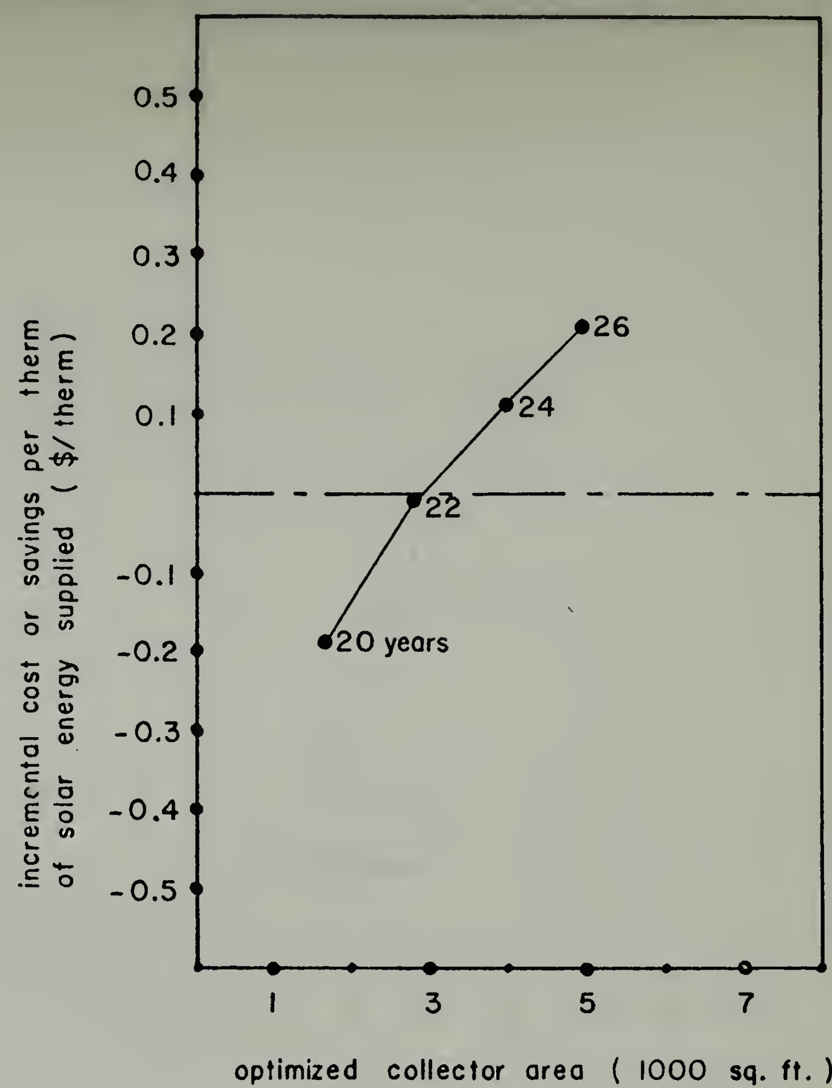


incremental value of solar energy supplied vs. optimized collector area

fig. 3.2.18 DHW & space- north terminal (installed cost = $ 1,442,830)

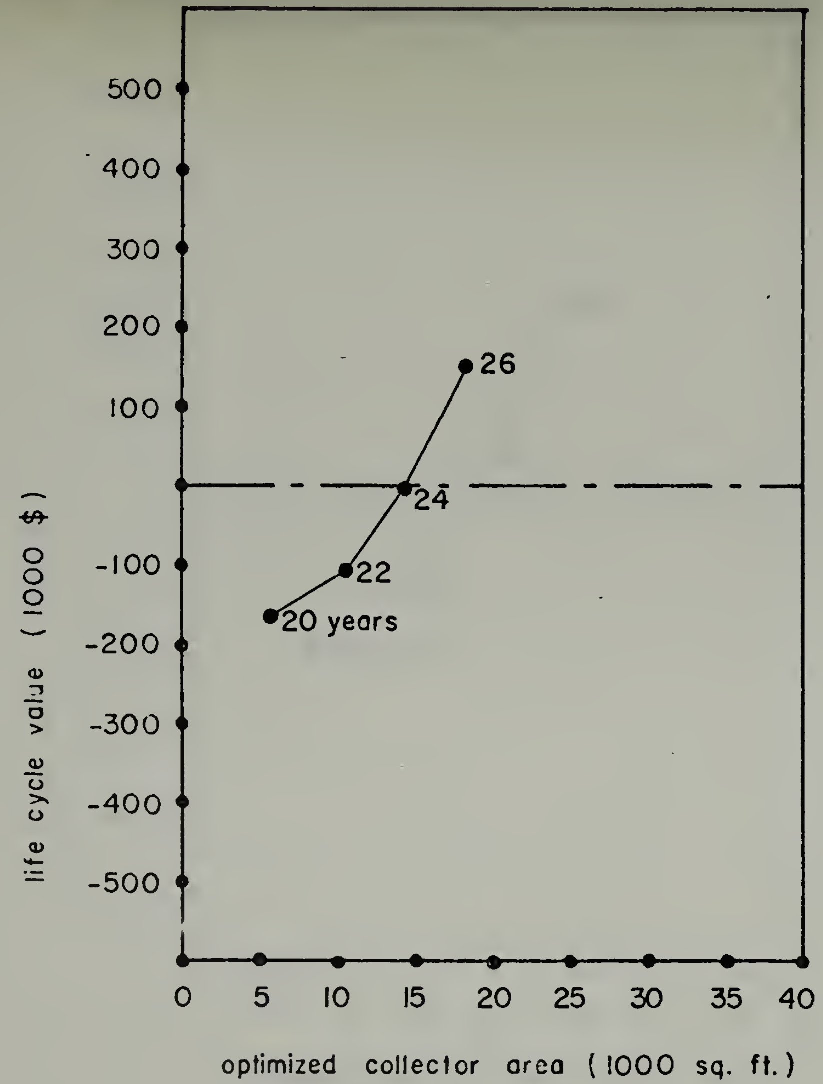


life cycle value vs. optimized collector area

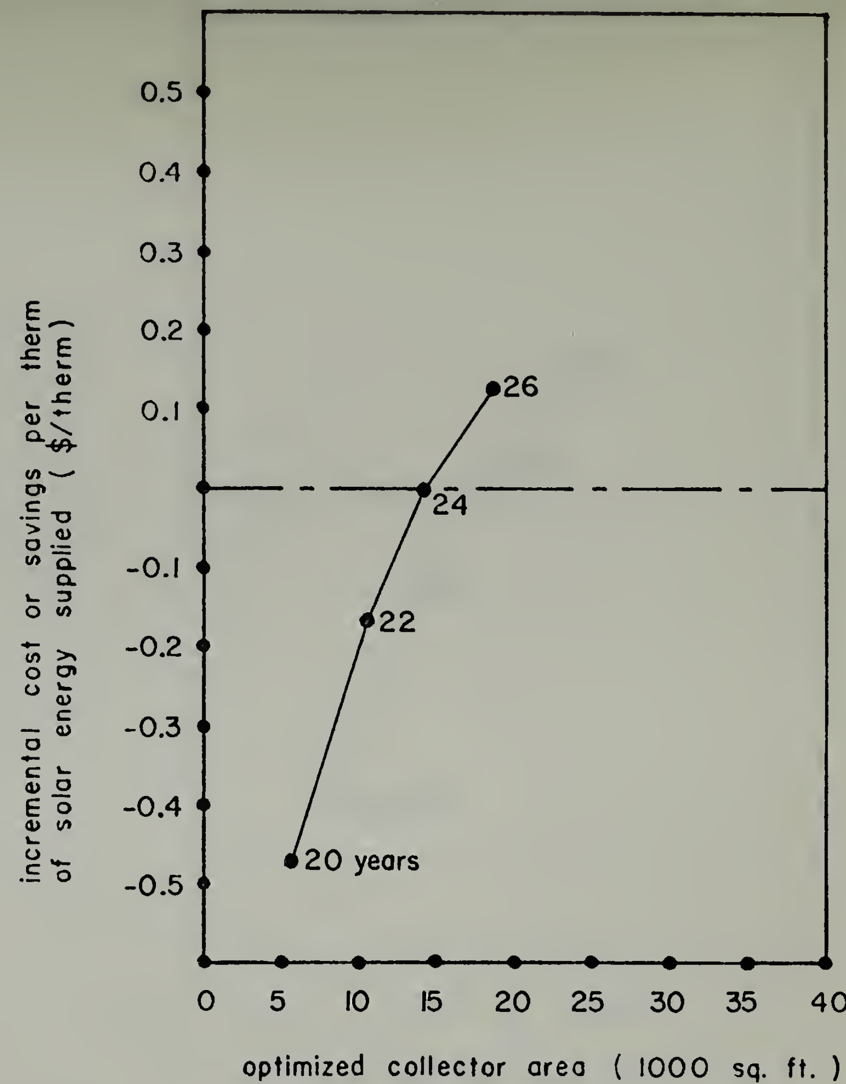


incremental value of solar energy supplied vs. optimized collector area

fig. 3.2.19 DHW- piers H & I (installed cost = $ 117,350)

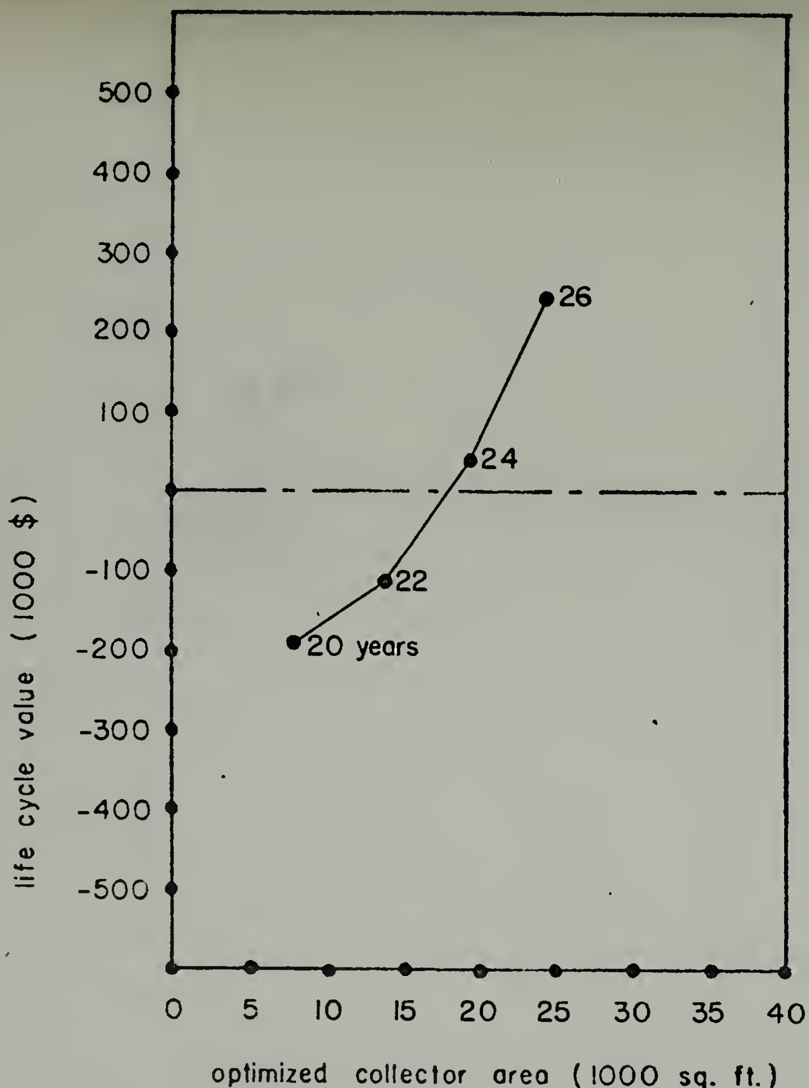


life cycle value vs. optimized collector area

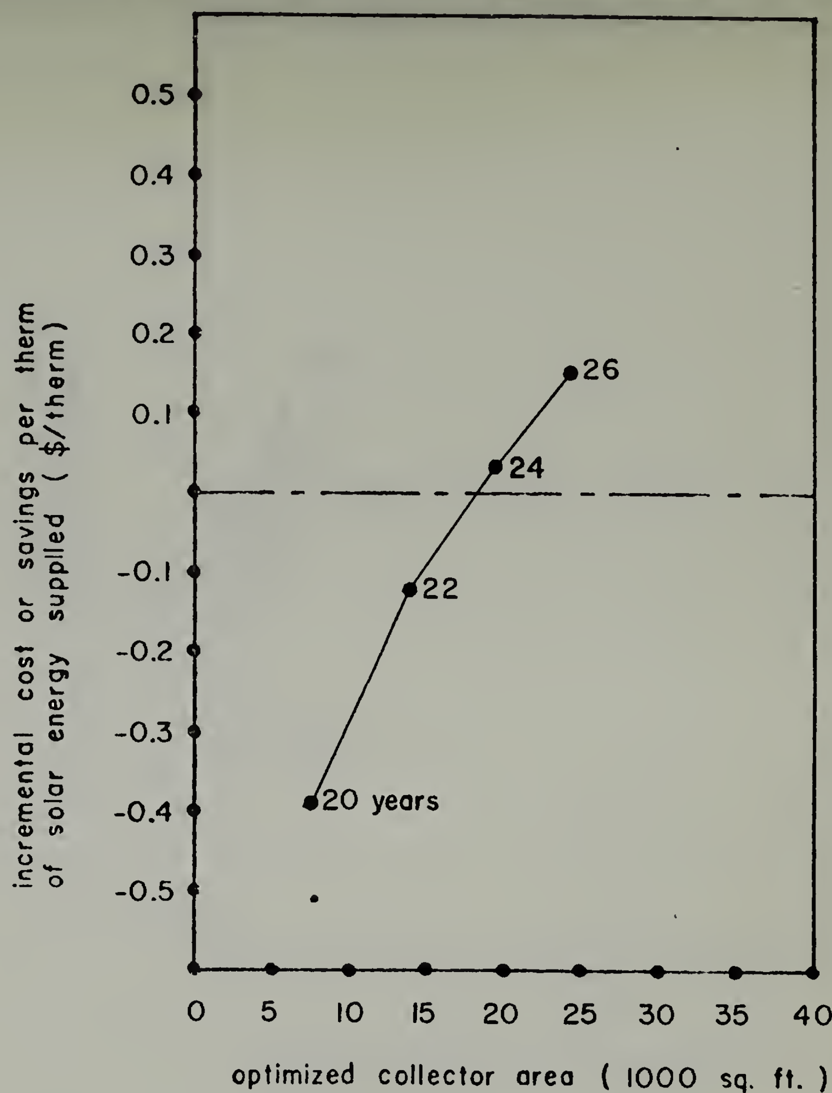


incremental value of solar energy supplied vs. optimized collector area

fig. 3.2.20 space- piers H & I (installed cost = $ 671,920)

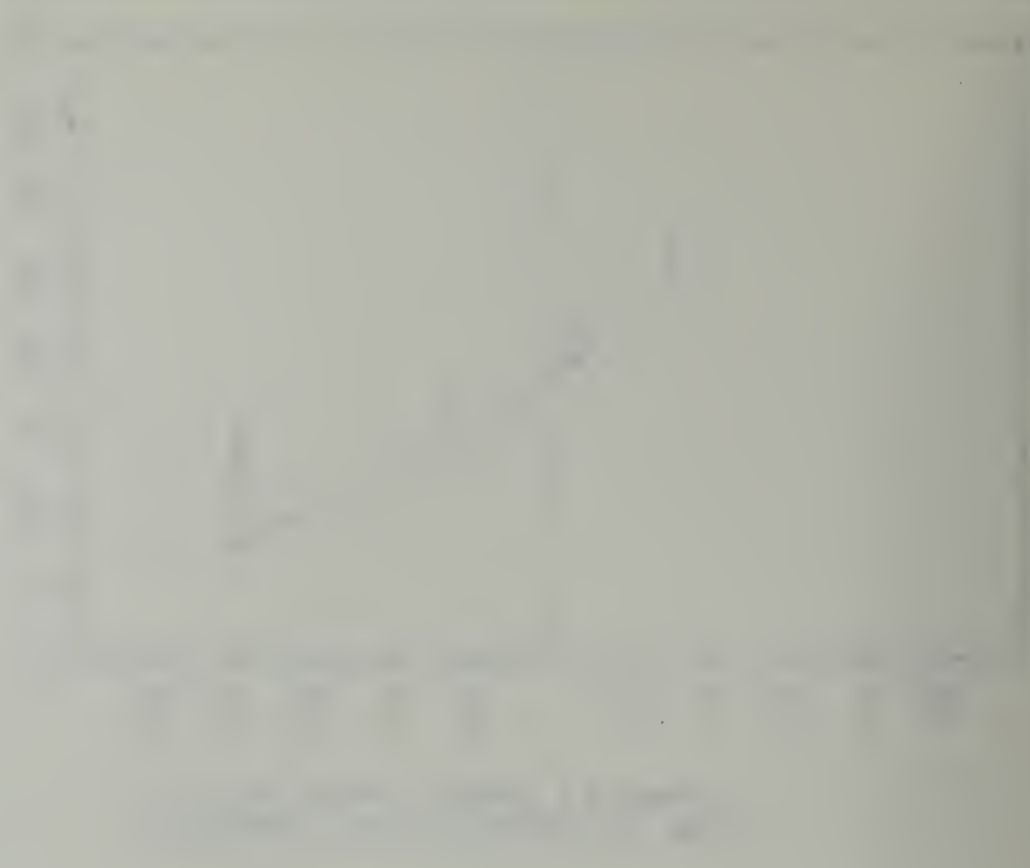


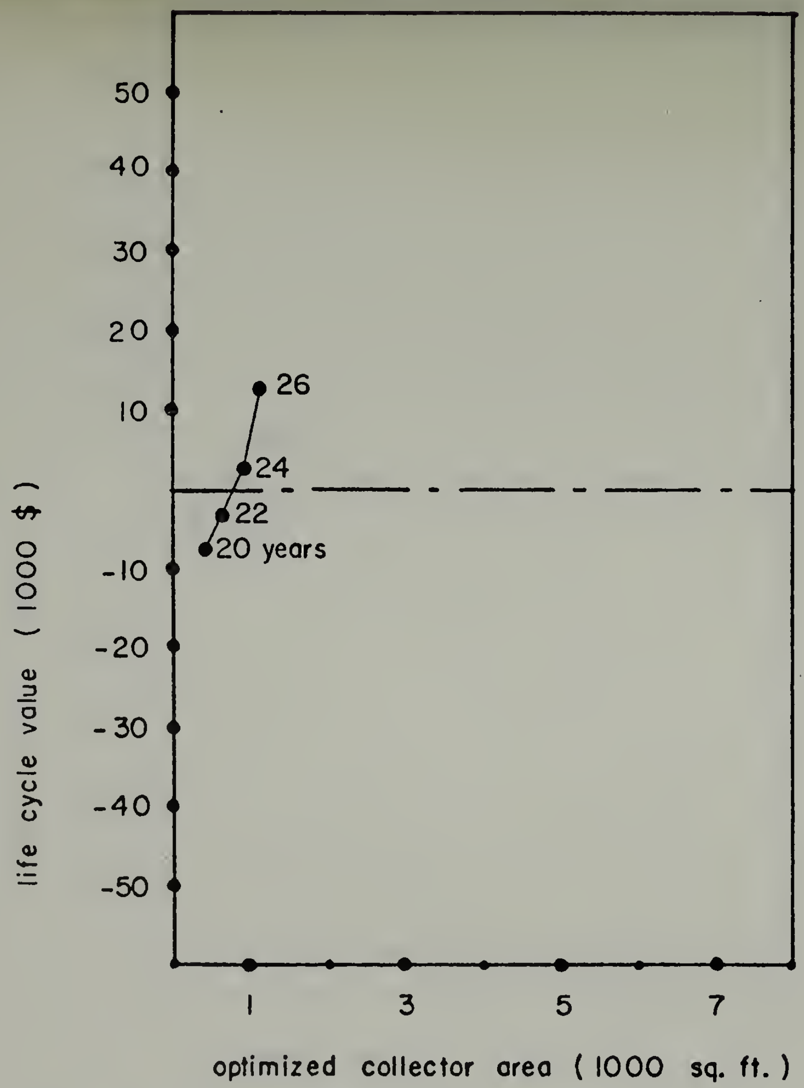
life cycle value vs. optimized collector area



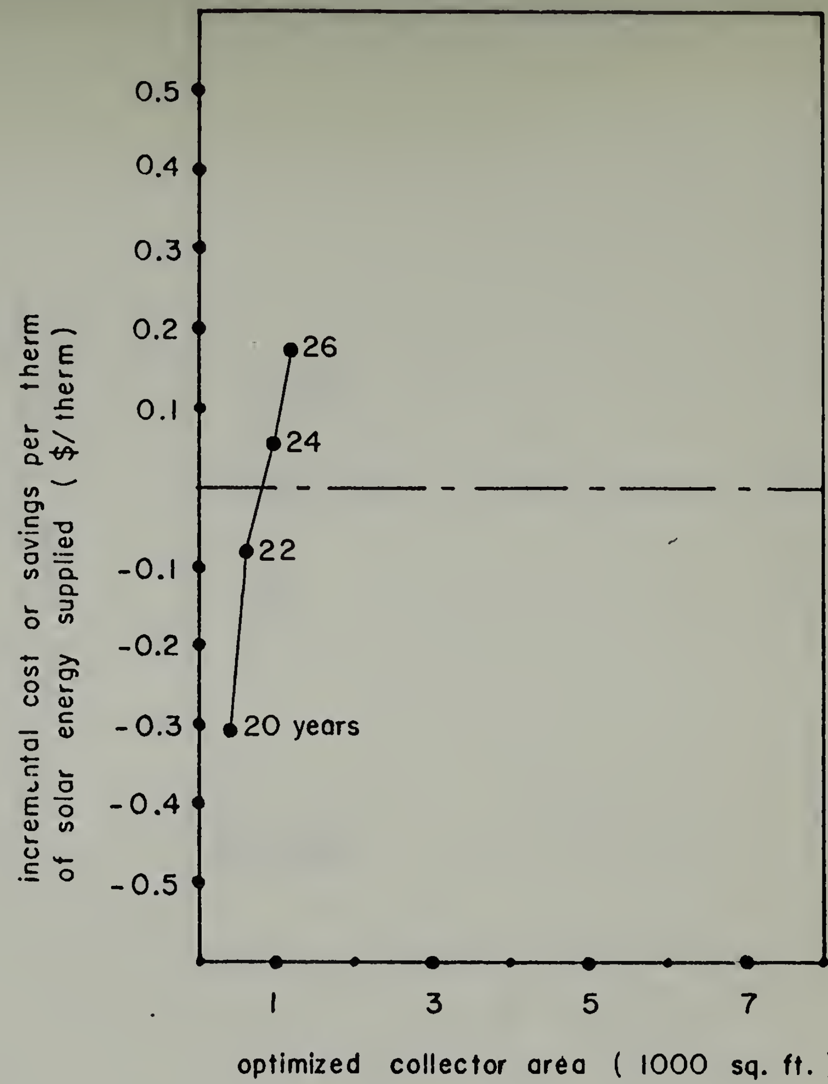
incremental value of solar energy supplied vs. optimized collector area

fig. 3.2.21 DHW & space- piers H & I (installed cost = $ 871,010)





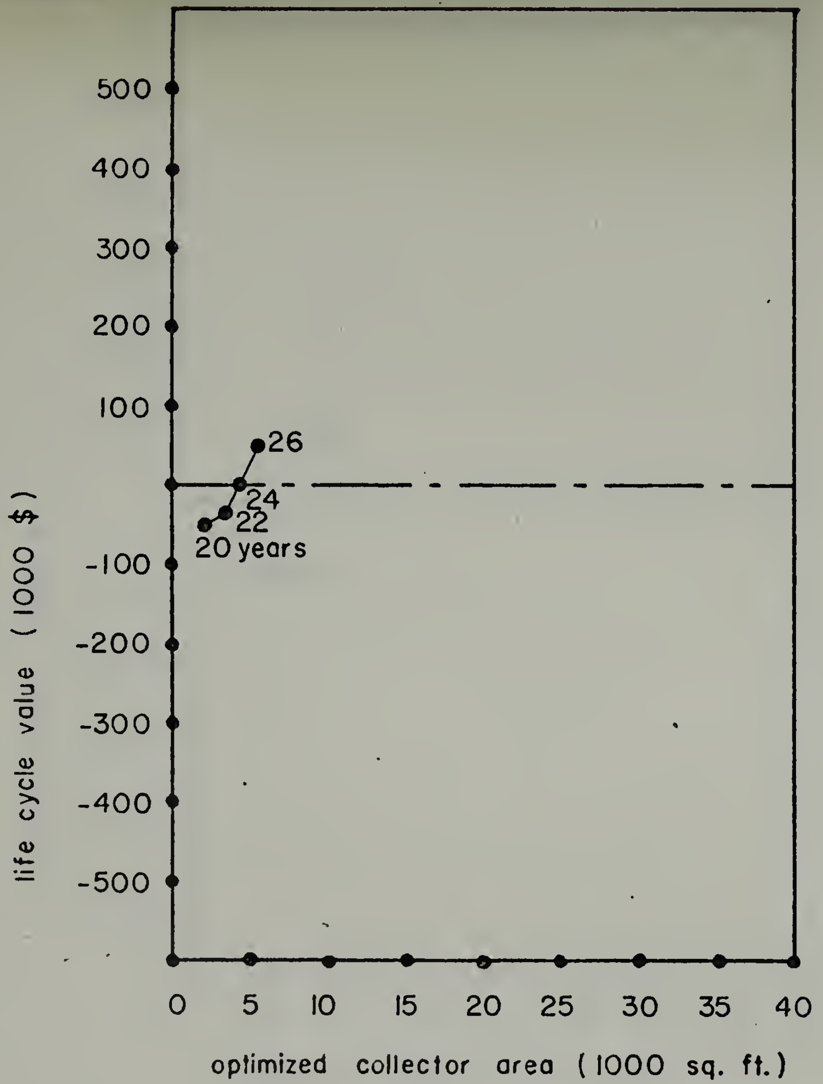
life cycle value vs. optimized collector area



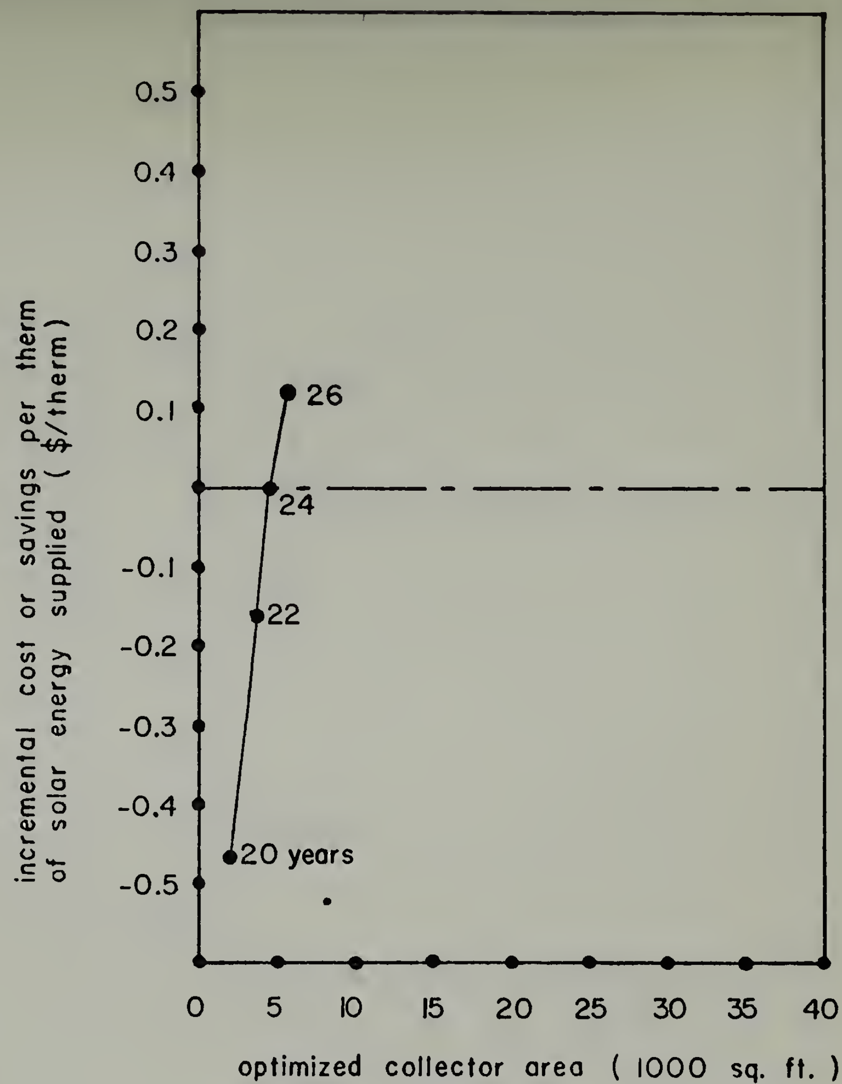
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport — solar feasibility study

fig. 3.2.22 DHW- pier B (installed cost = $ 29,450)



life cycle value vs. optimized collector area



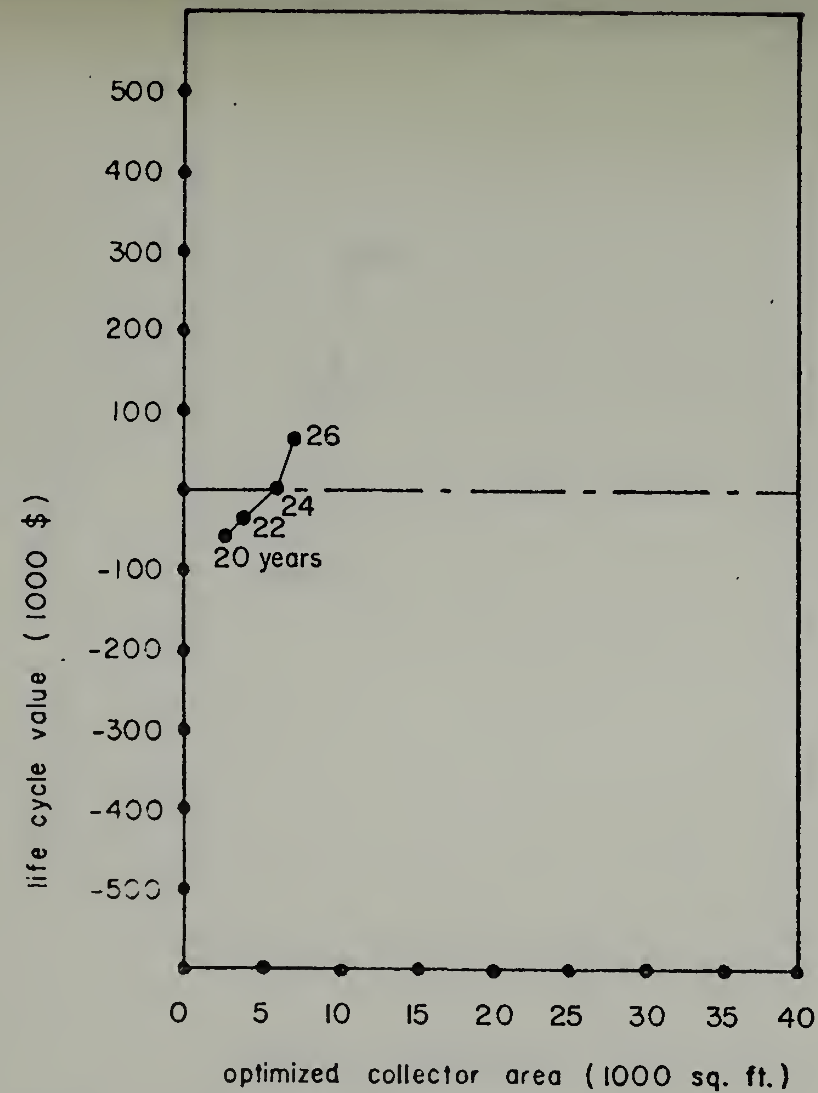
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport

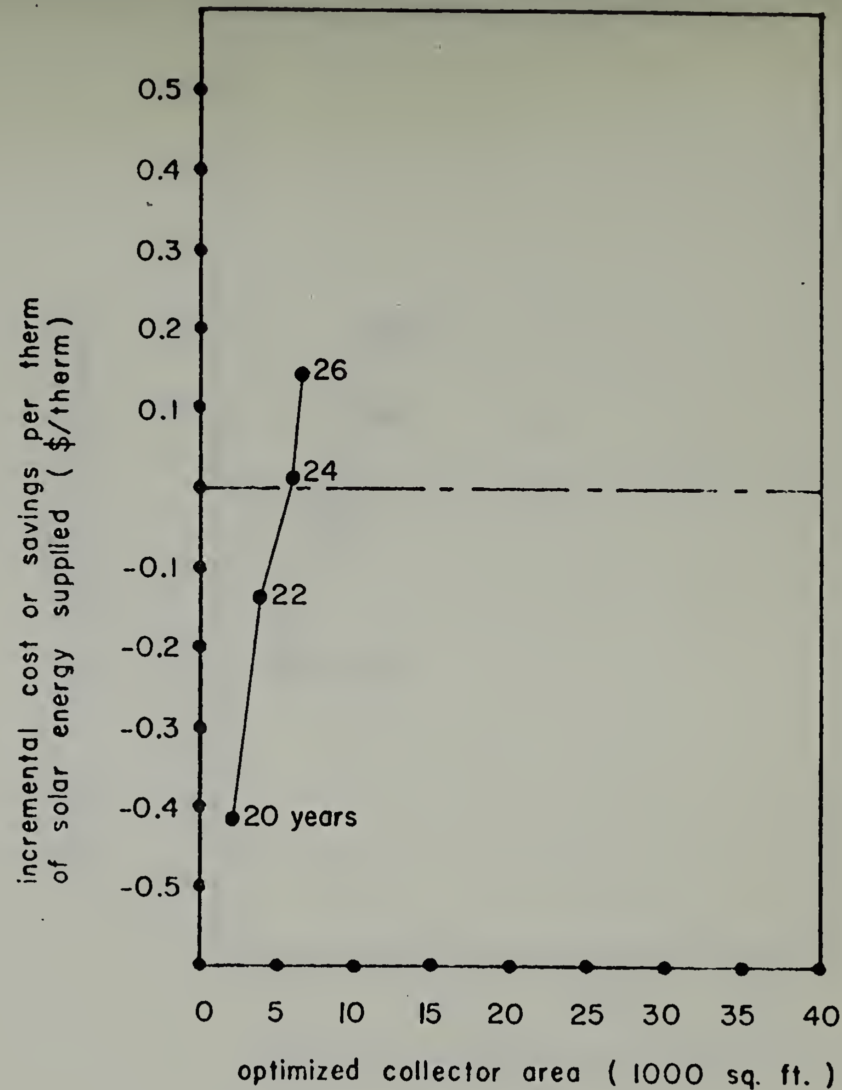
solar feasibility study

fig. 3.2.23

space- pier B (installed cost = $ 204,050)



life cycle value vs. optimized collector area

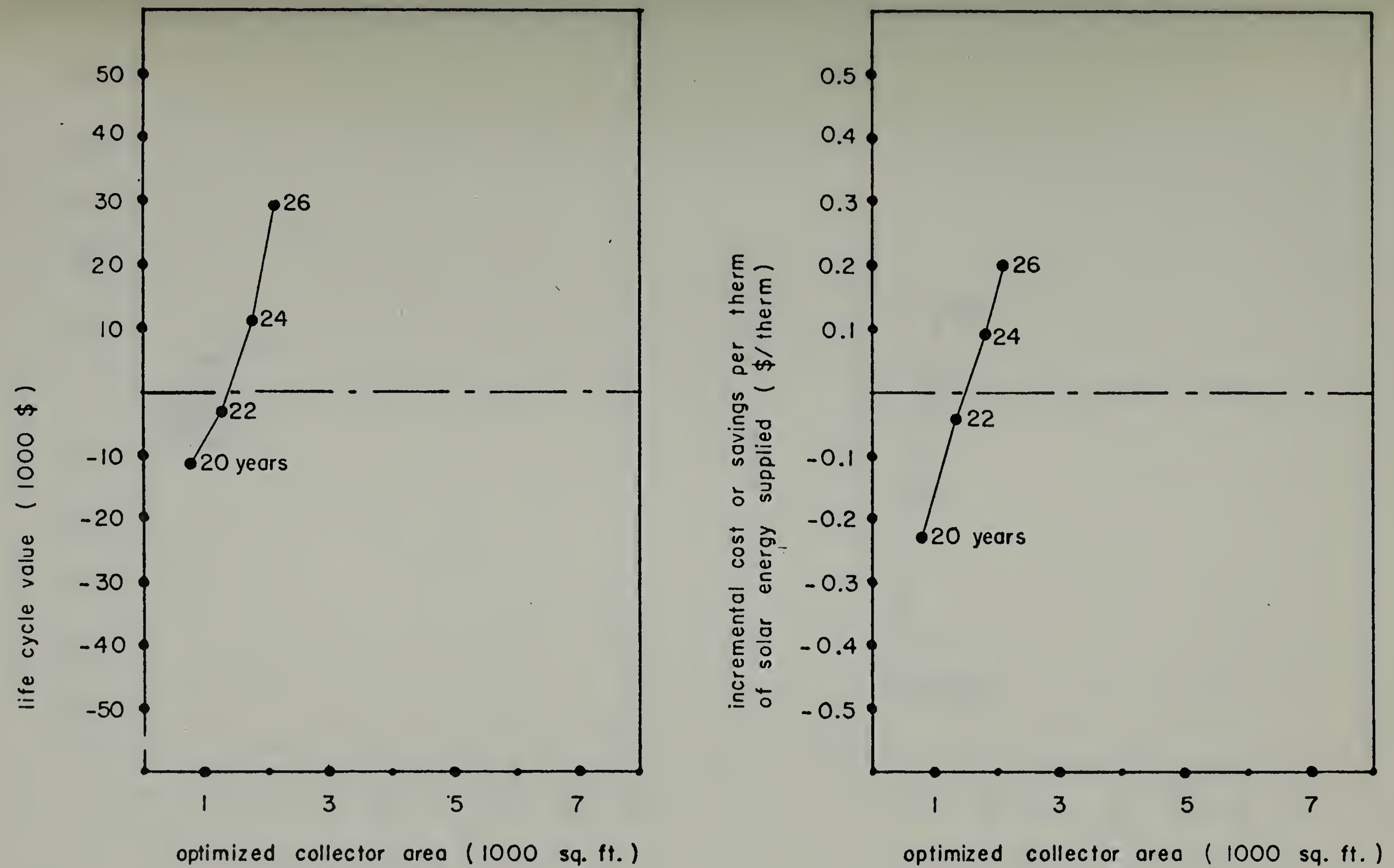


incremental value of solar energy supplied vs. optimized collector area

san francisco international airport

solar feasibility study

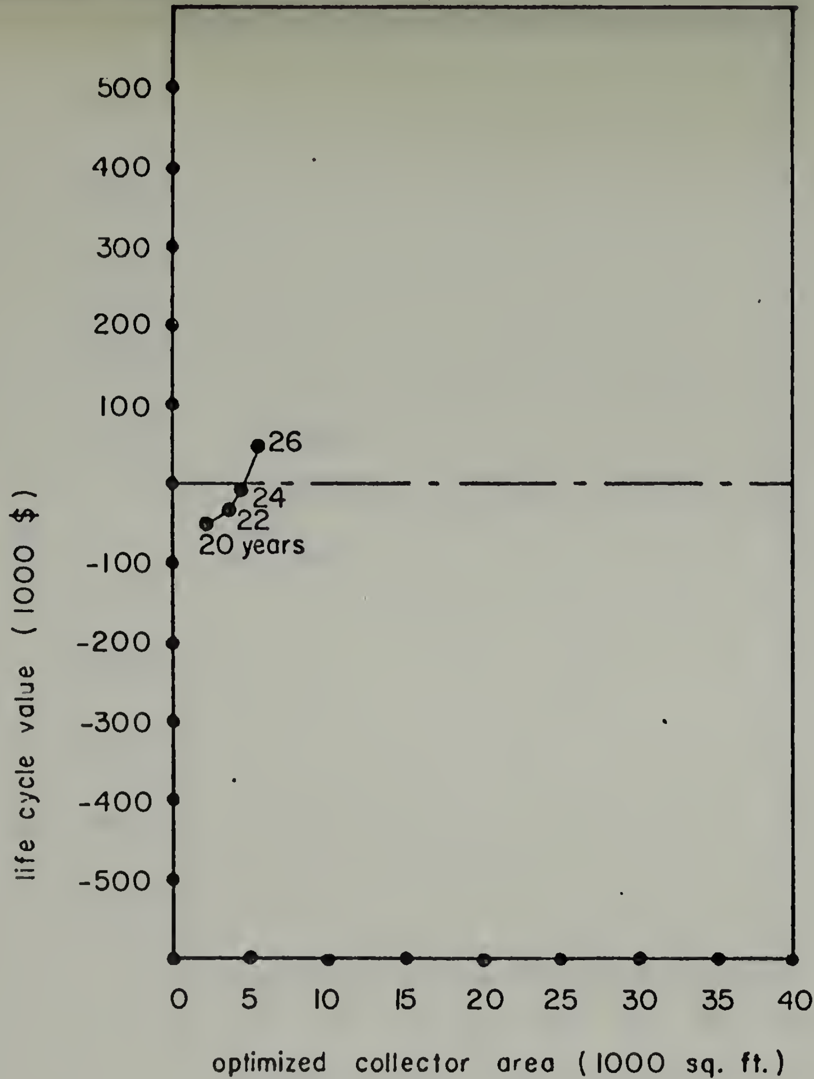
fig. 3.2.24 DHW & space- pier B (installed cost = $ 252,800)



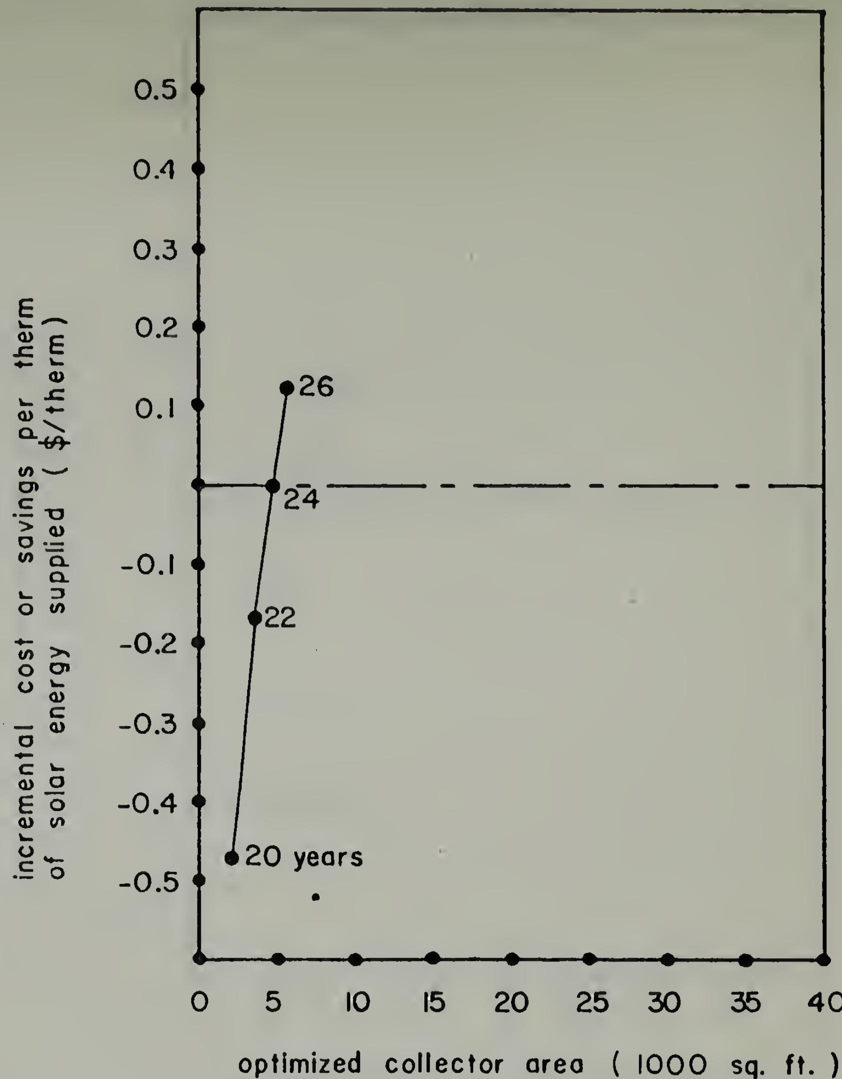
life cycle value vs. optimized collector area

Incremental value of solar energy supplied vs. optimized collector area

fig. 3.2.25 DHW- pier C (installed cost = $ 54,050)

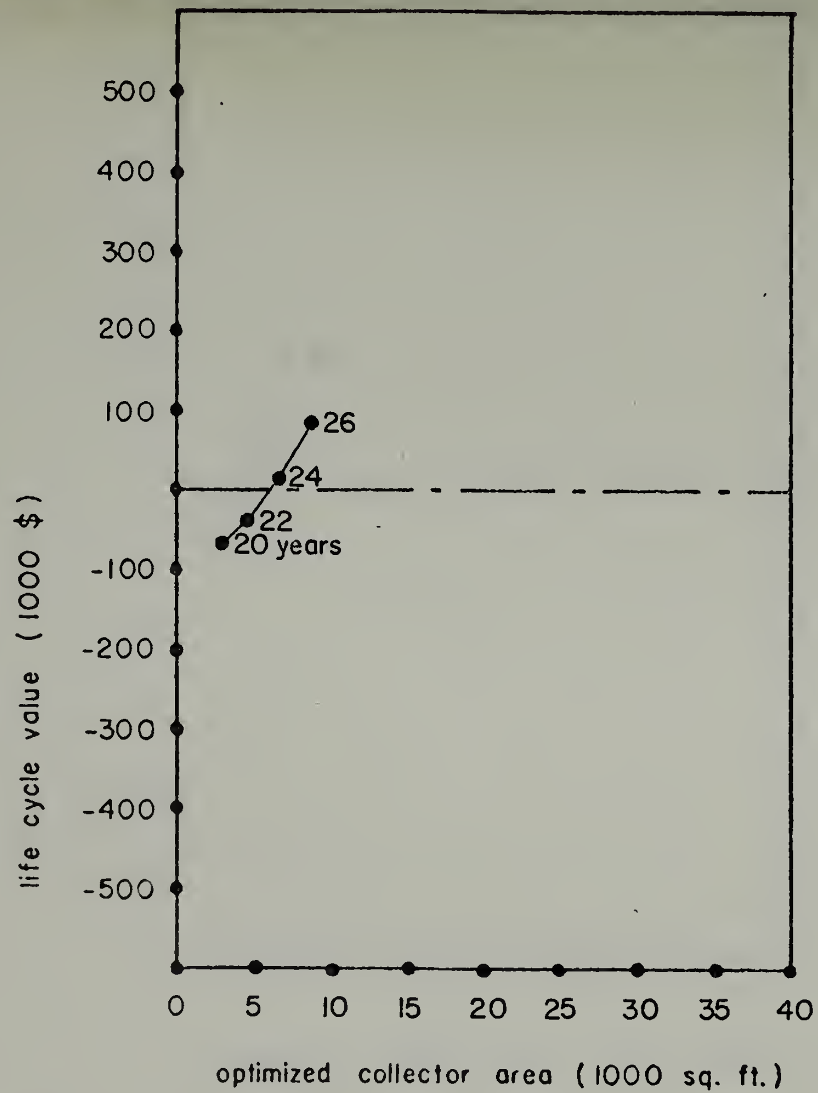


life cycle value vs. optimized collector area

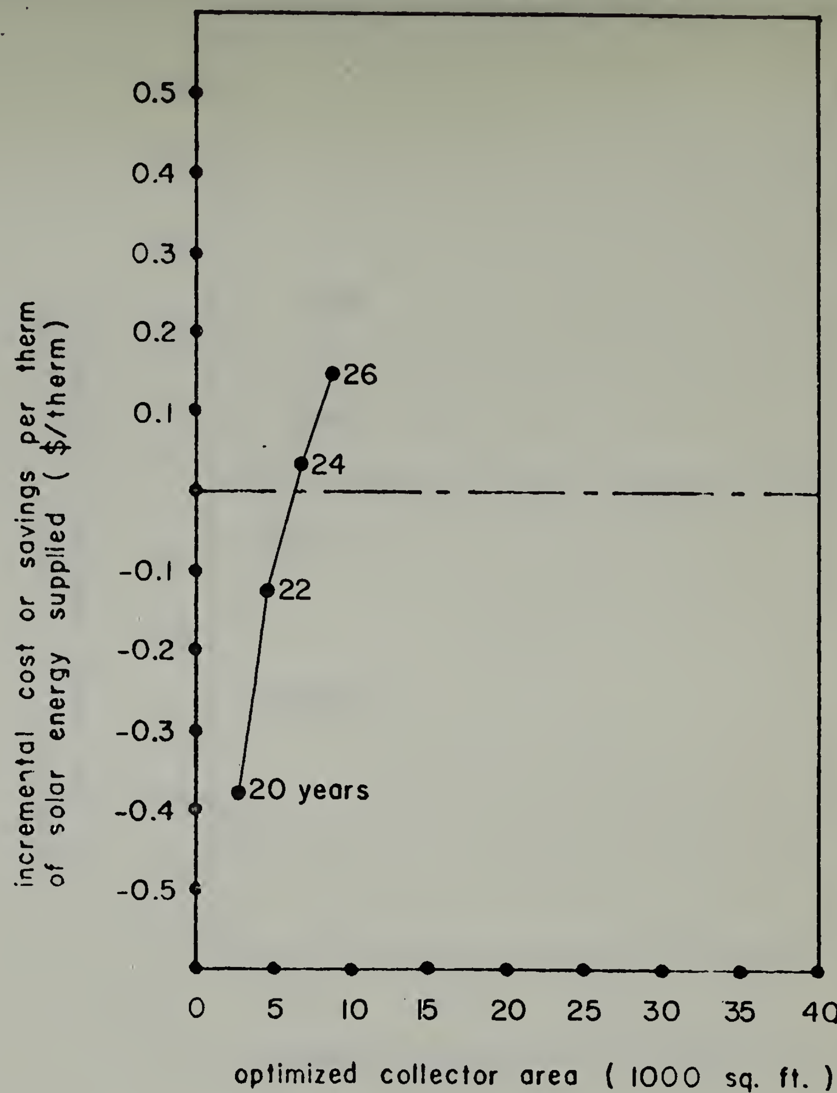


incremental value of solar energy supplied vs. optimized collector area

fig. 3.2.26 space- pier C (installed cost = $ 204,050)



life cycle value vs. optimized collector area



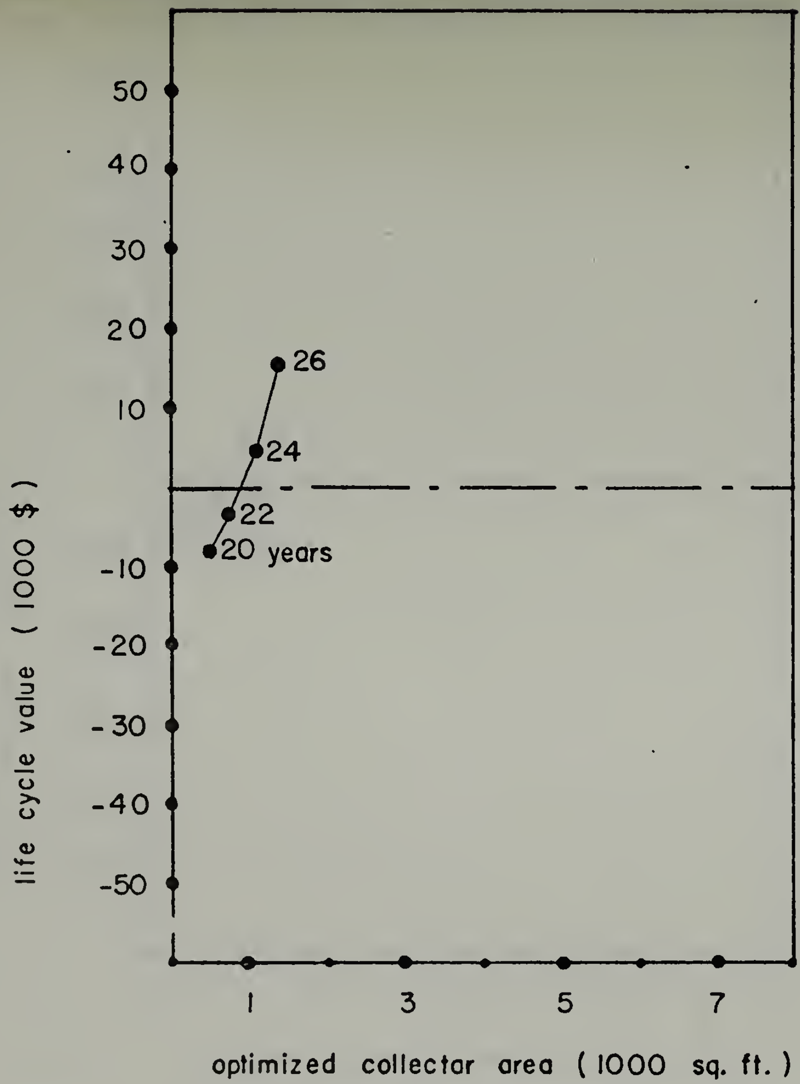
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport

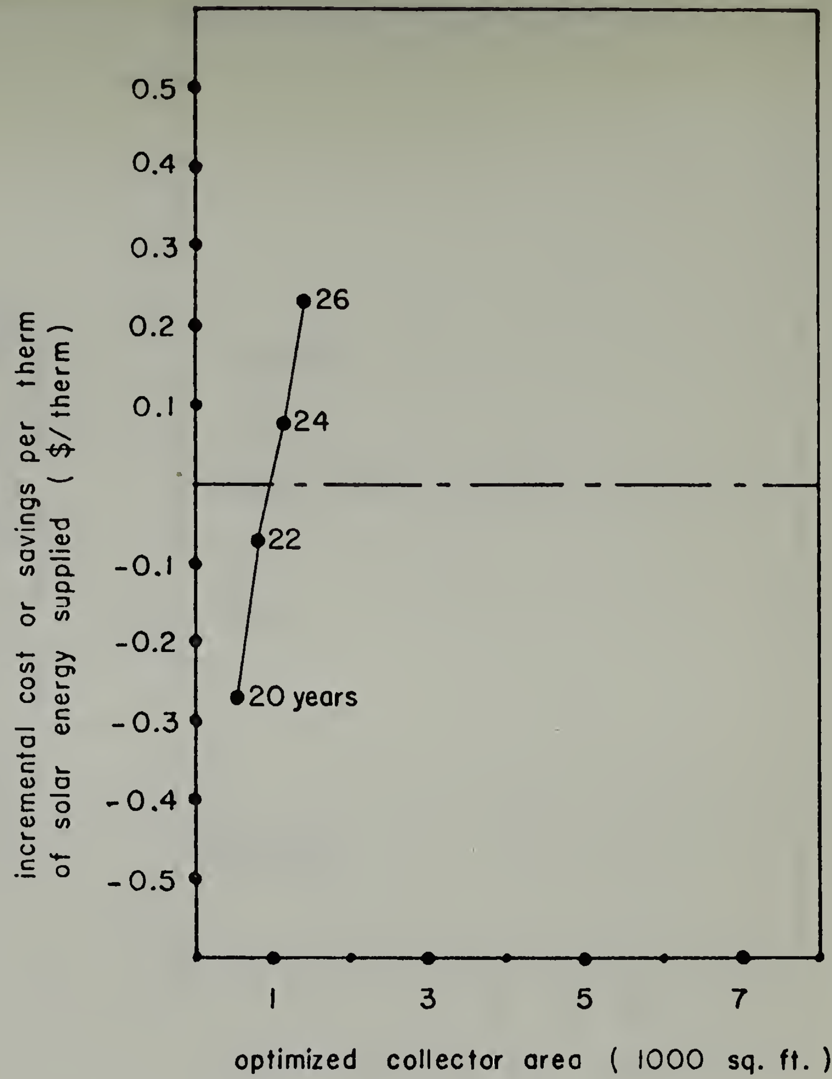
solar feasibility study

fig. 3.2.27

DHW & space- pier C (installed cost = $ 293,310)



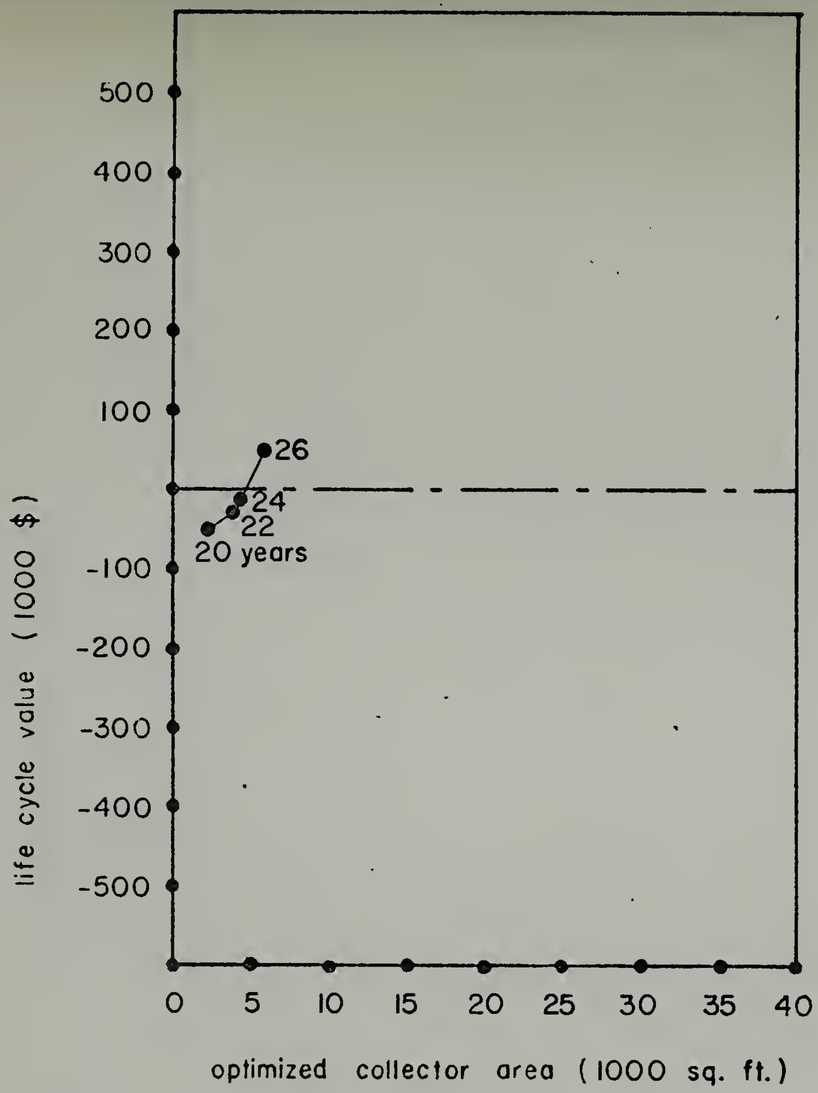
life cycle value v.s. optimized collector area



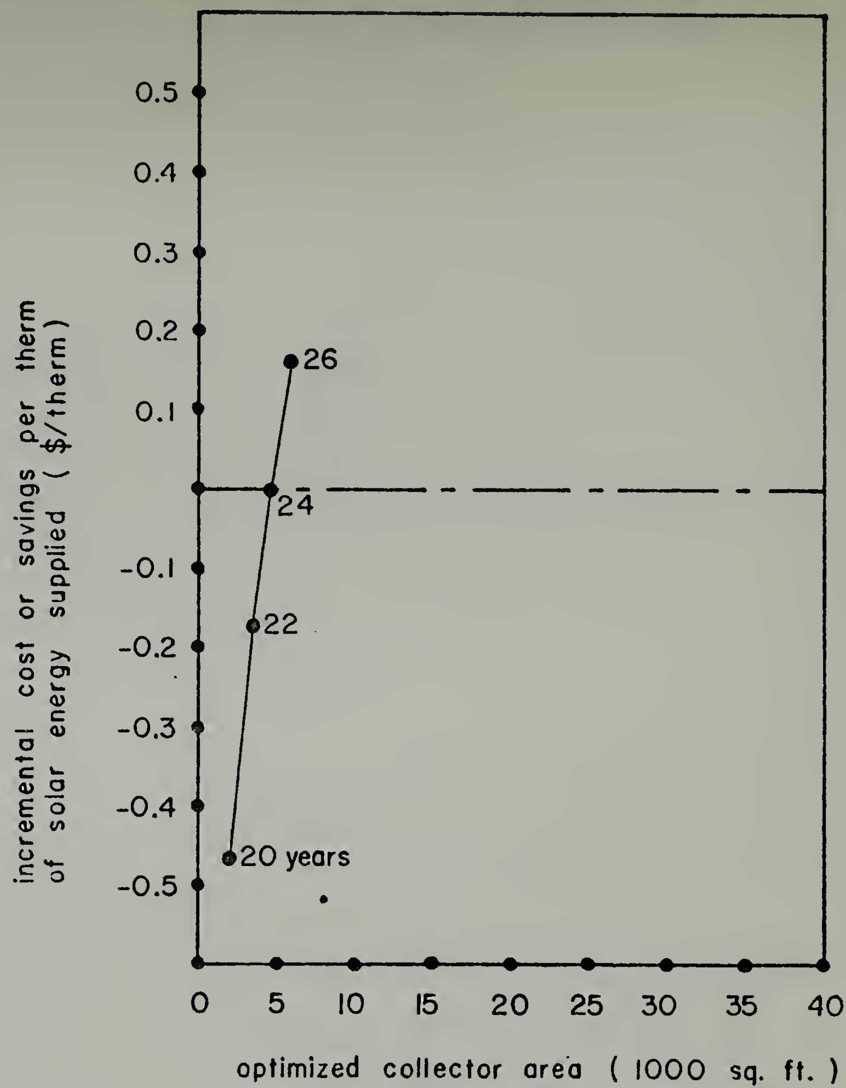
Incremental value of solar energy supplied vs. optimized collector area

san francisco international airport solar feasibility study

fig. 3.2.28 DHW- pier D (installed cost = $ 33,940)



life cycle value vs. optimized collector area



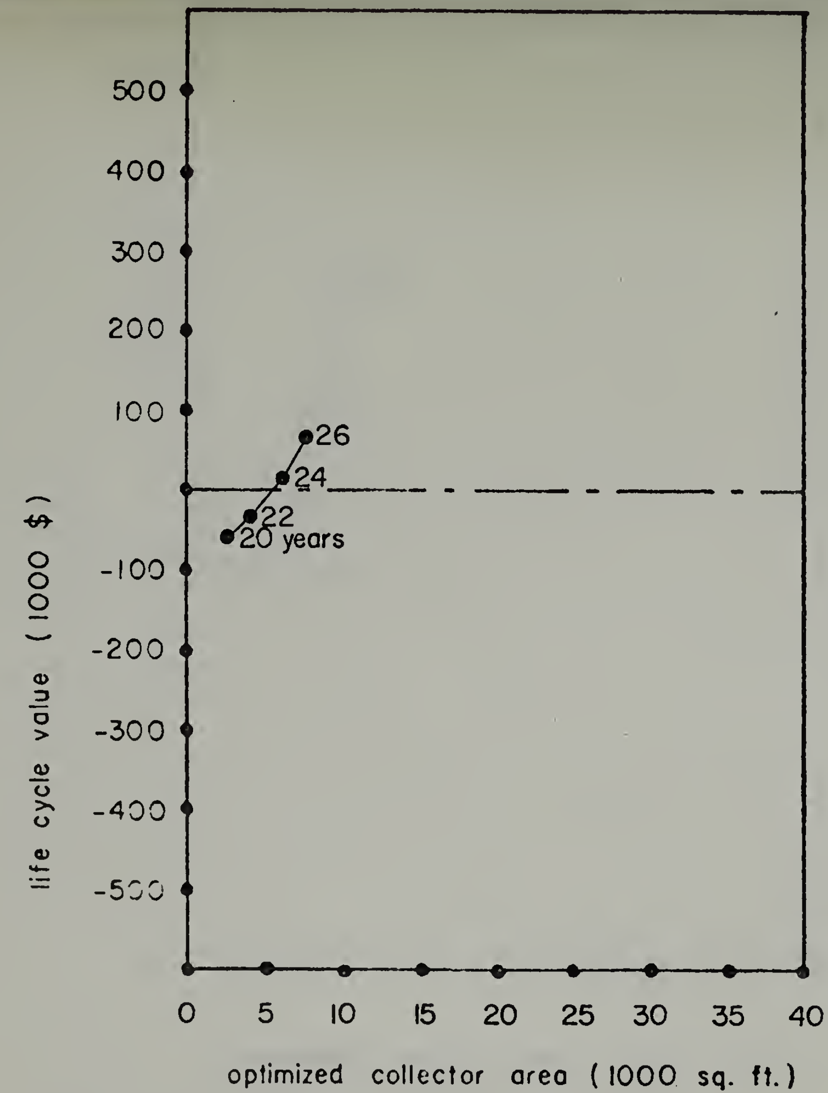
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport

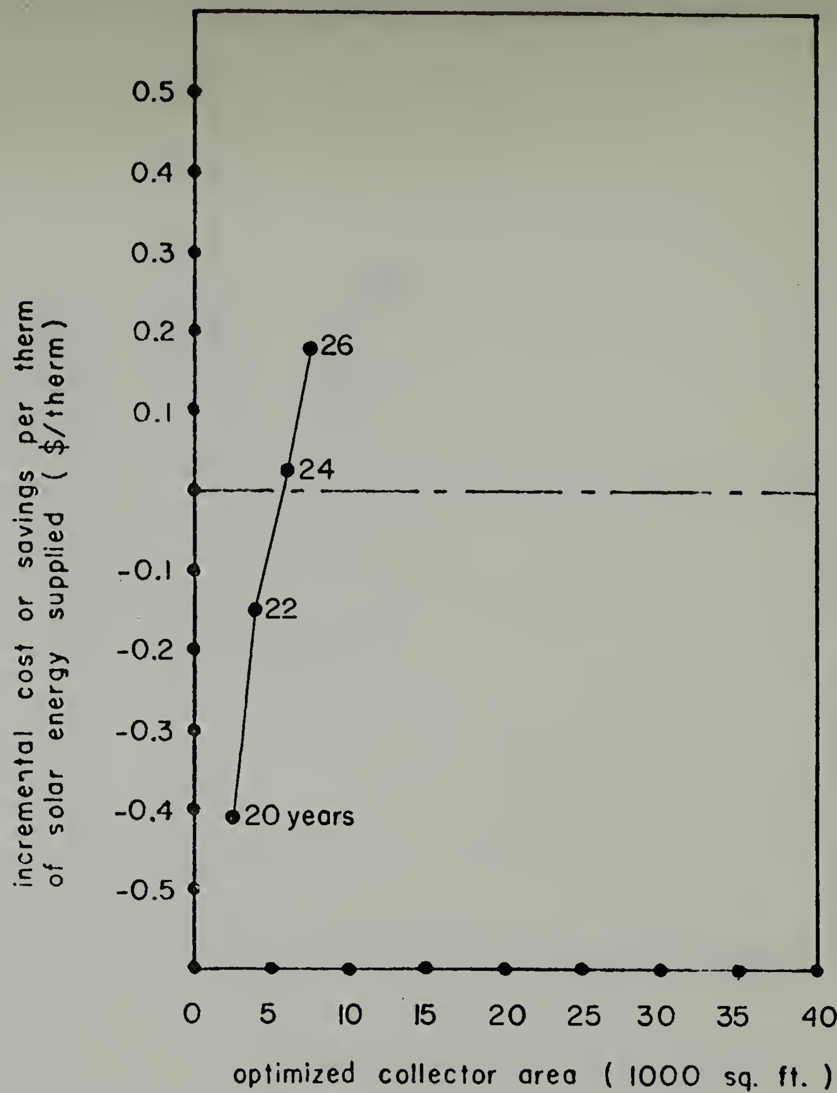
solar feasibility study

fig. 3.2.29

space- pier D (installed cost = $204,050)



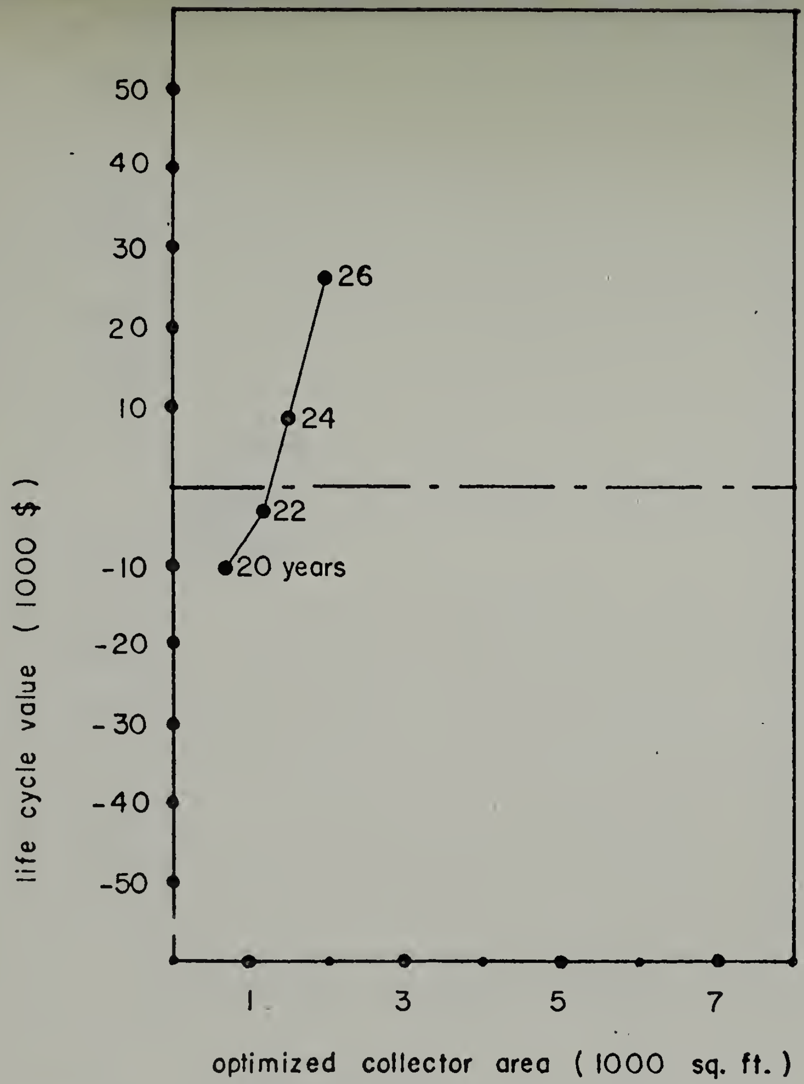
life cycle value vs. optimized collector area



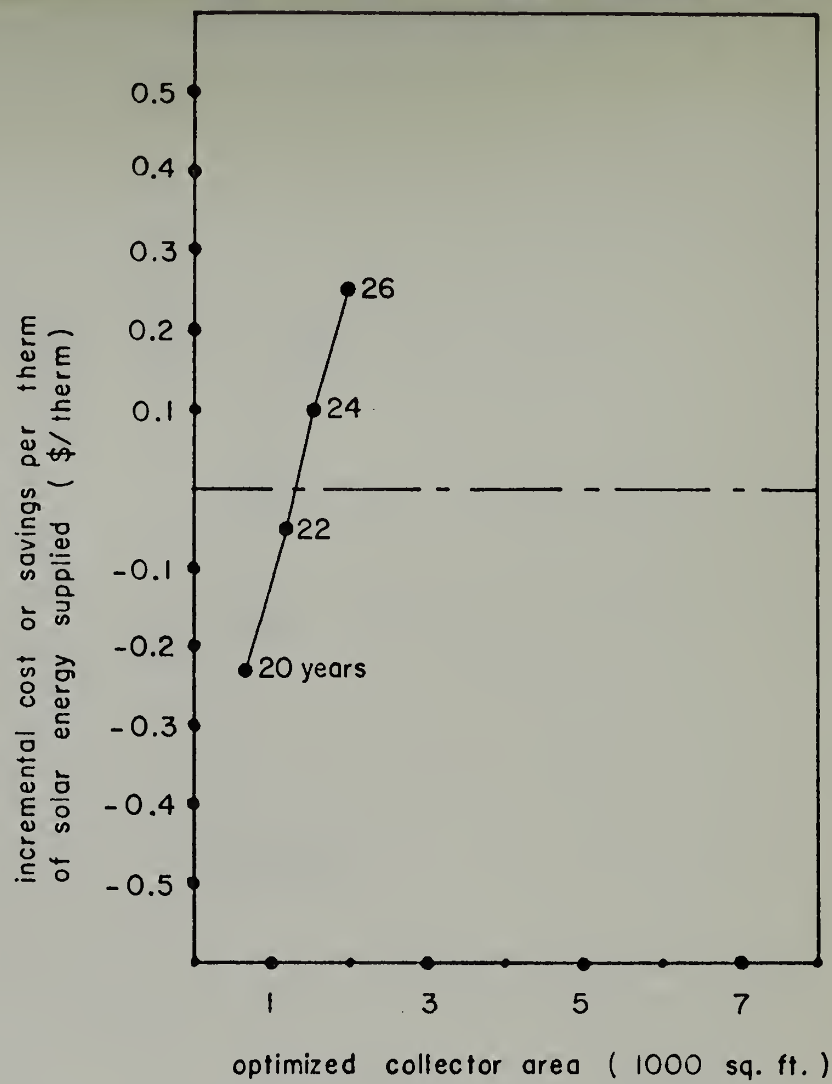
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport — solar feasibility study

fig. 3.2.30 DHW & space- pier D (installed cost = $ 260,310)



life cycle value vs. optimized collector area



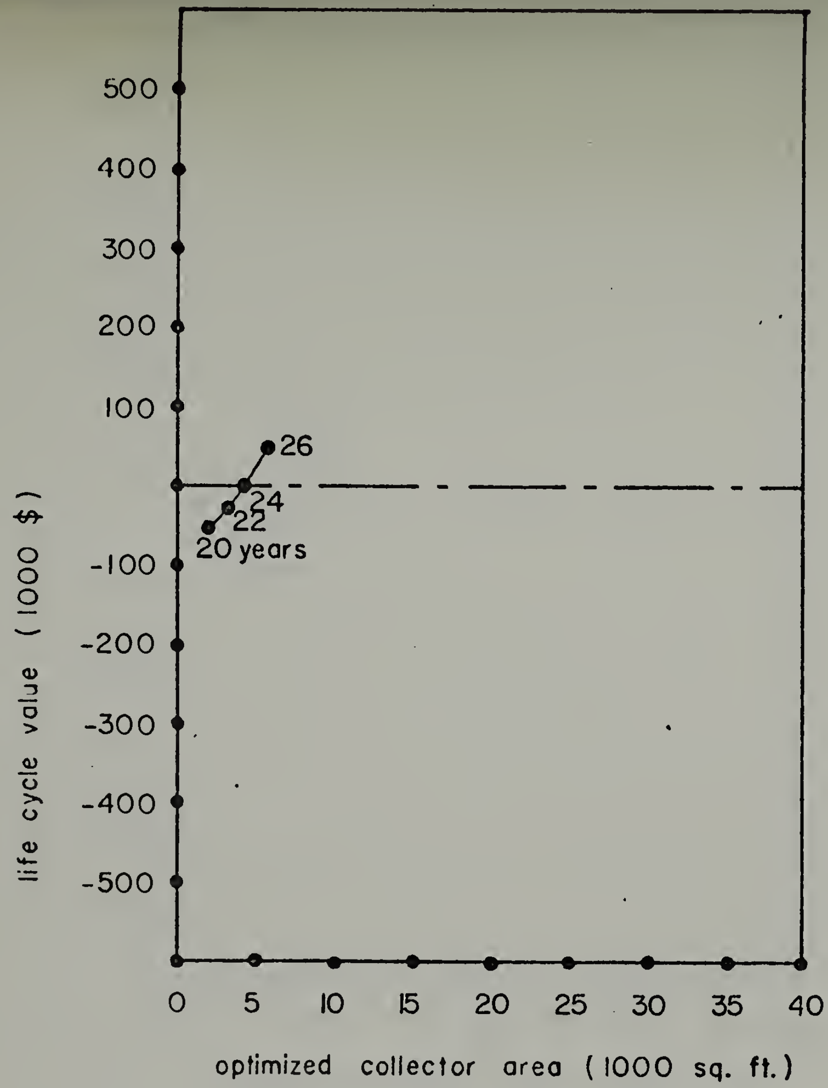
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport

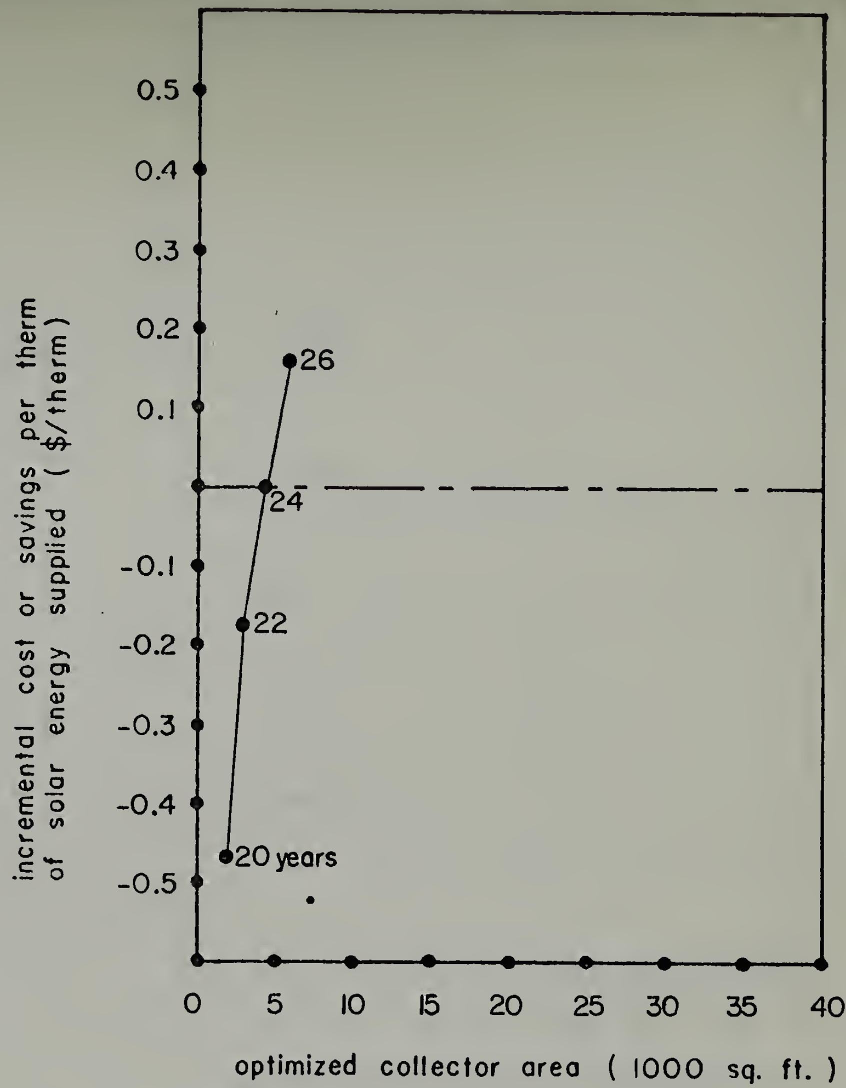
solar feasibility study

fig. 3.2.31

DHW- pier E (installed cost = $ 49,410)



life cycle value vs. optimized collector area



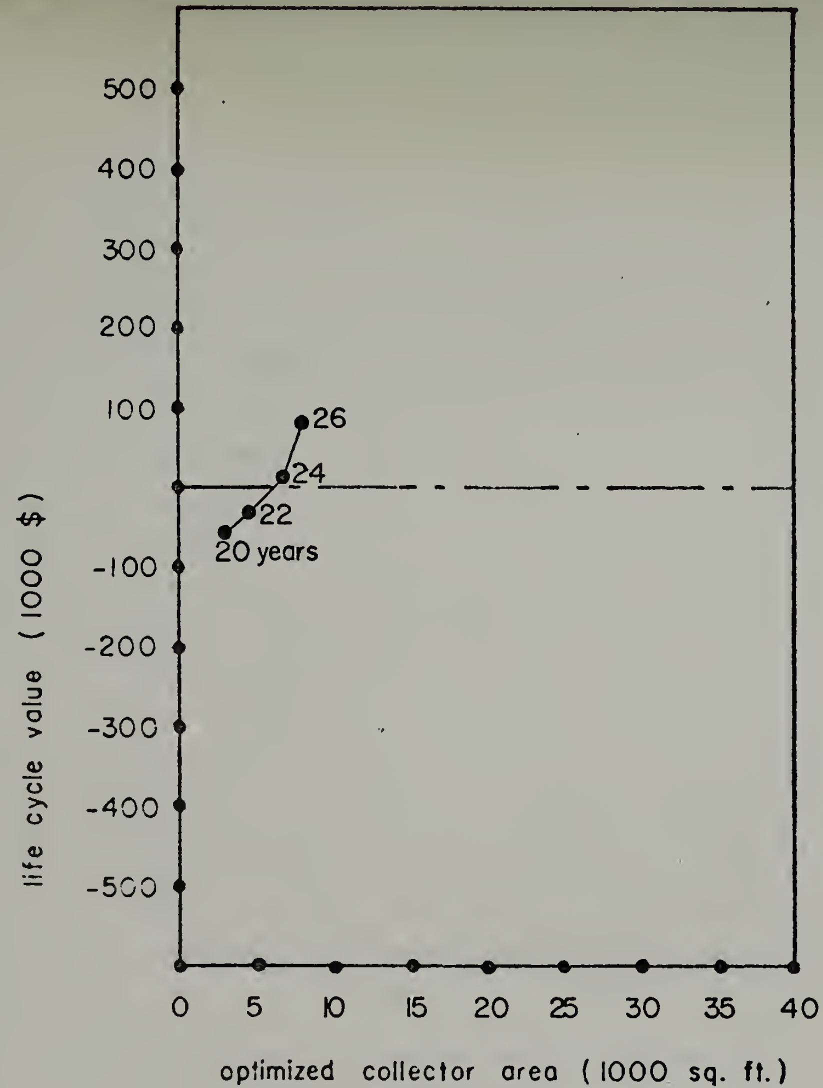
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport

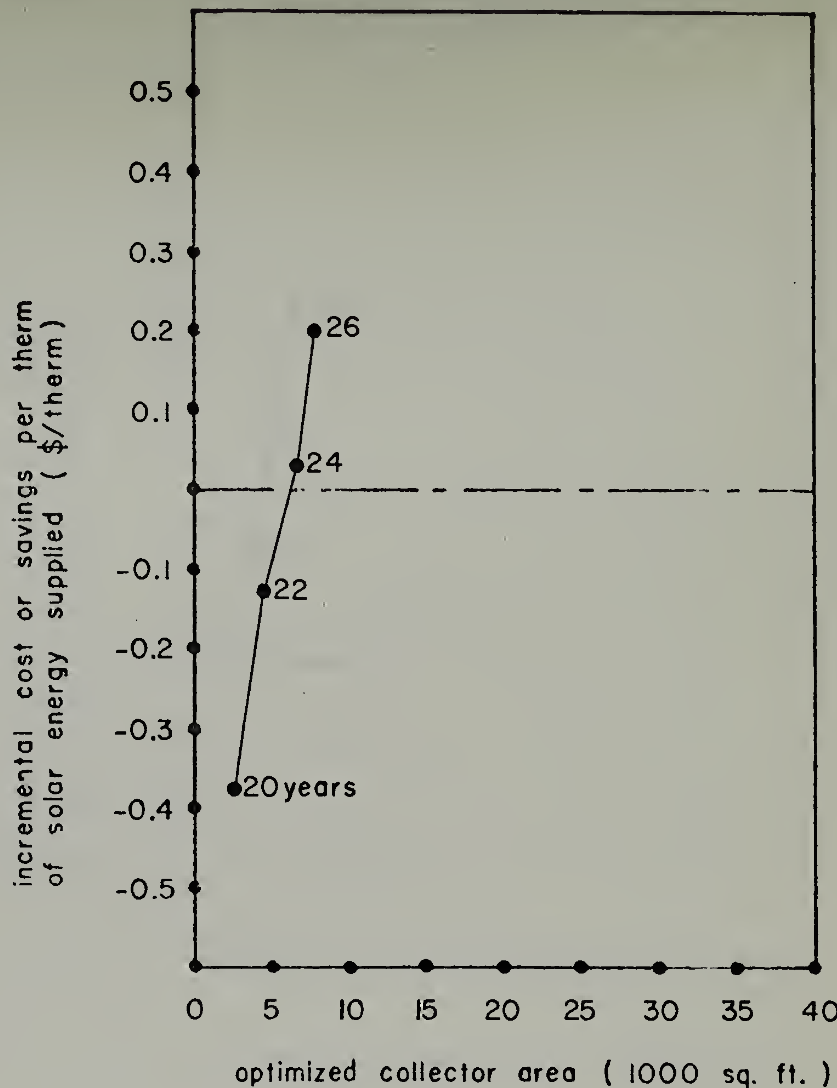
solar feasibility study

fig. 3.2.32

space- pier E (installed cost = $ 194,350)



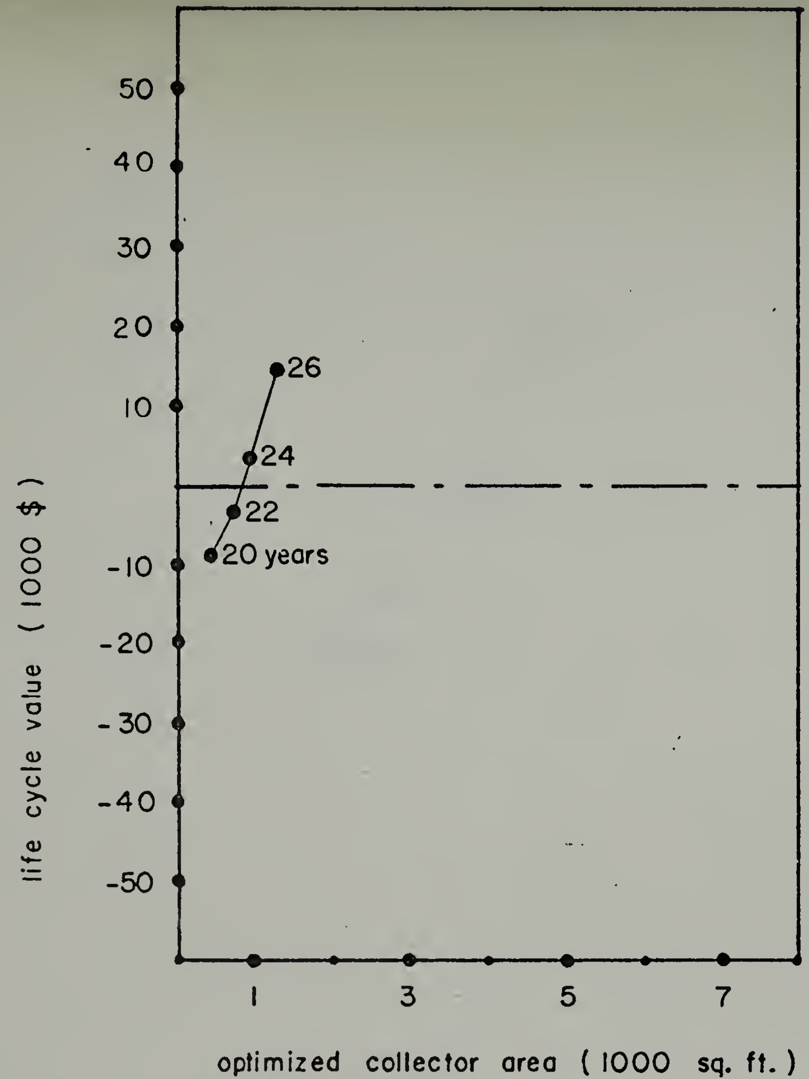
life cycle value vs. optimized collector area



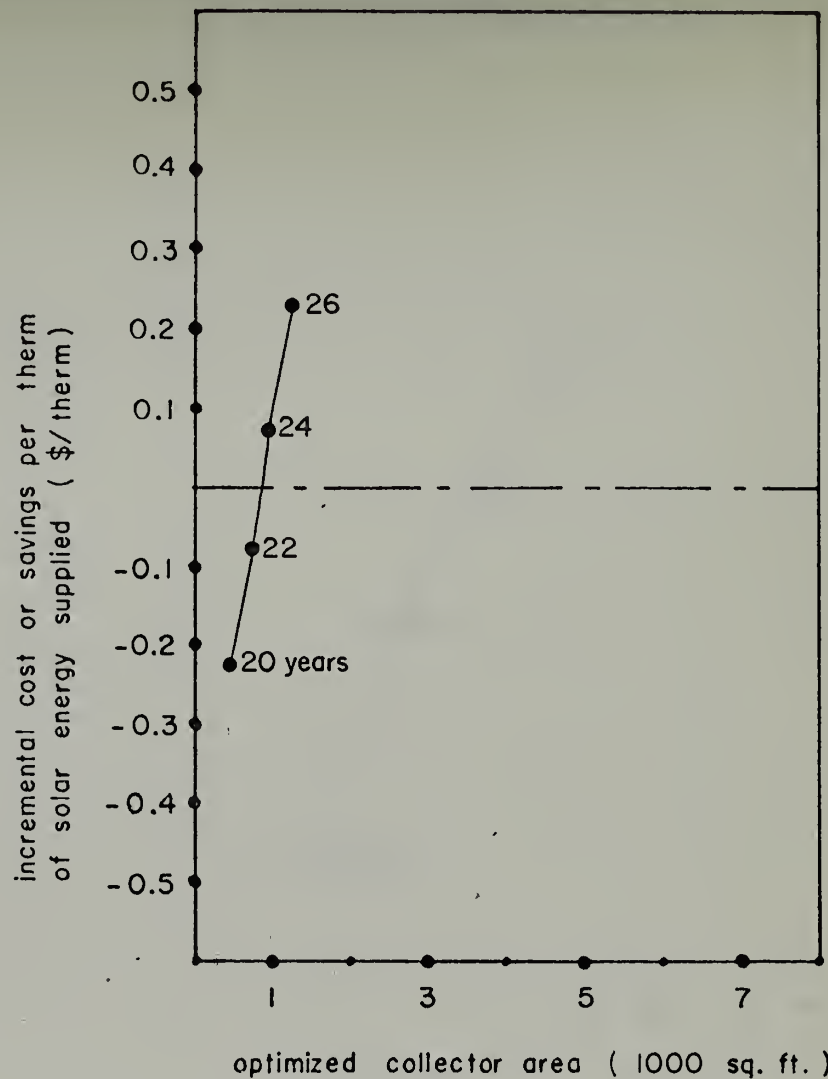
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport — solar feasibility study

fig. 3.2.33 DHW & space-pier E (installed cost = $ 275,930)



life cycle value vs. optimized collector area

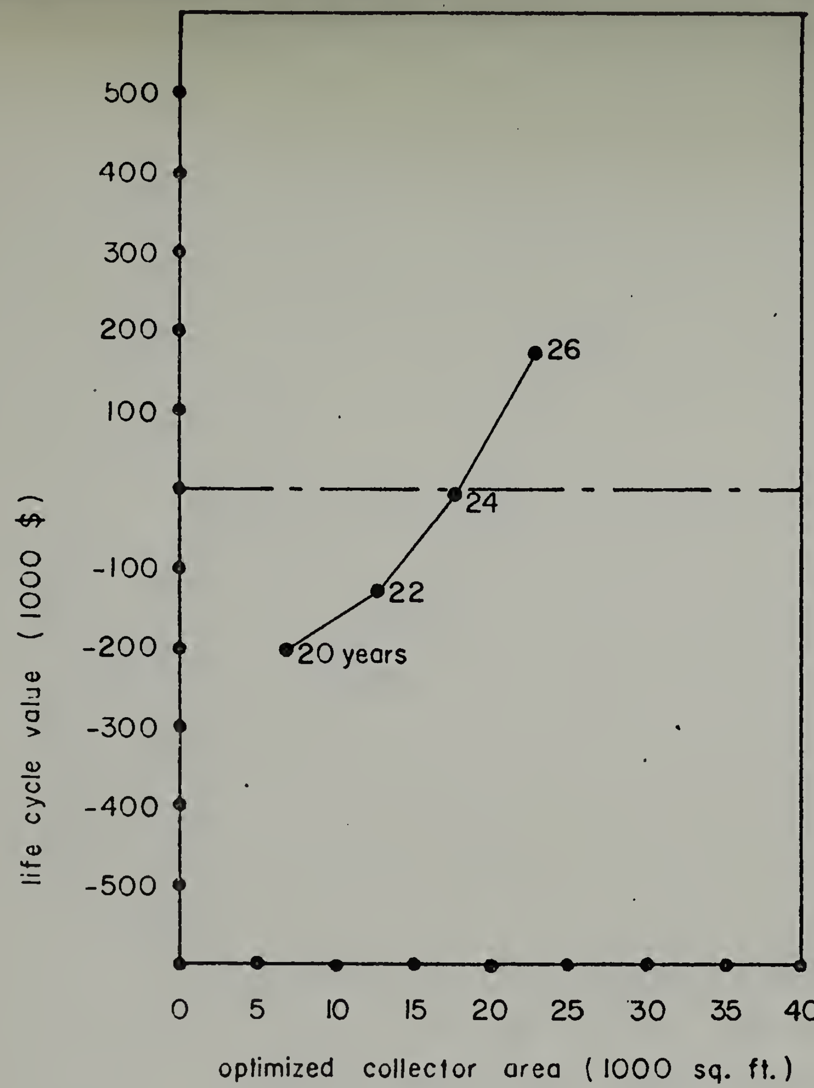


Incremental value of solar energy supplied vs. optimized collector area

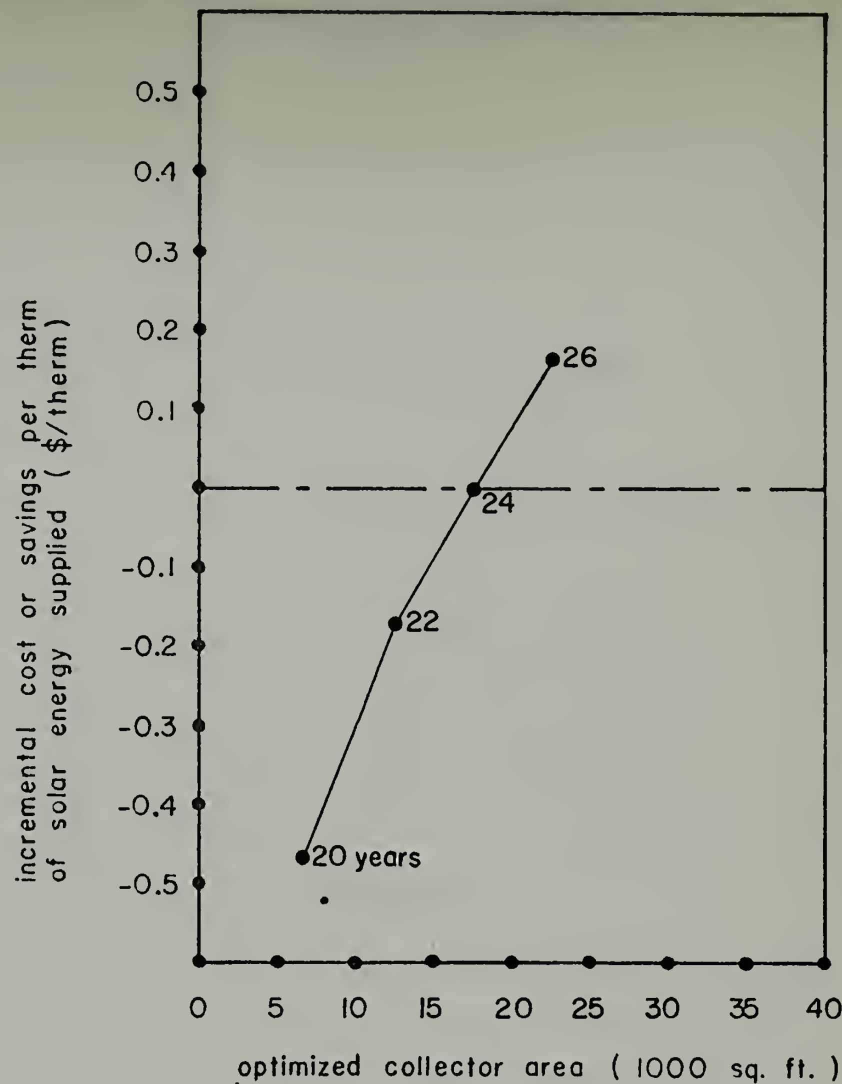
san francisco international airport

solar feasibility study

fig. 3.2.34 DHW- pier F (installed cost = $ 31,580)



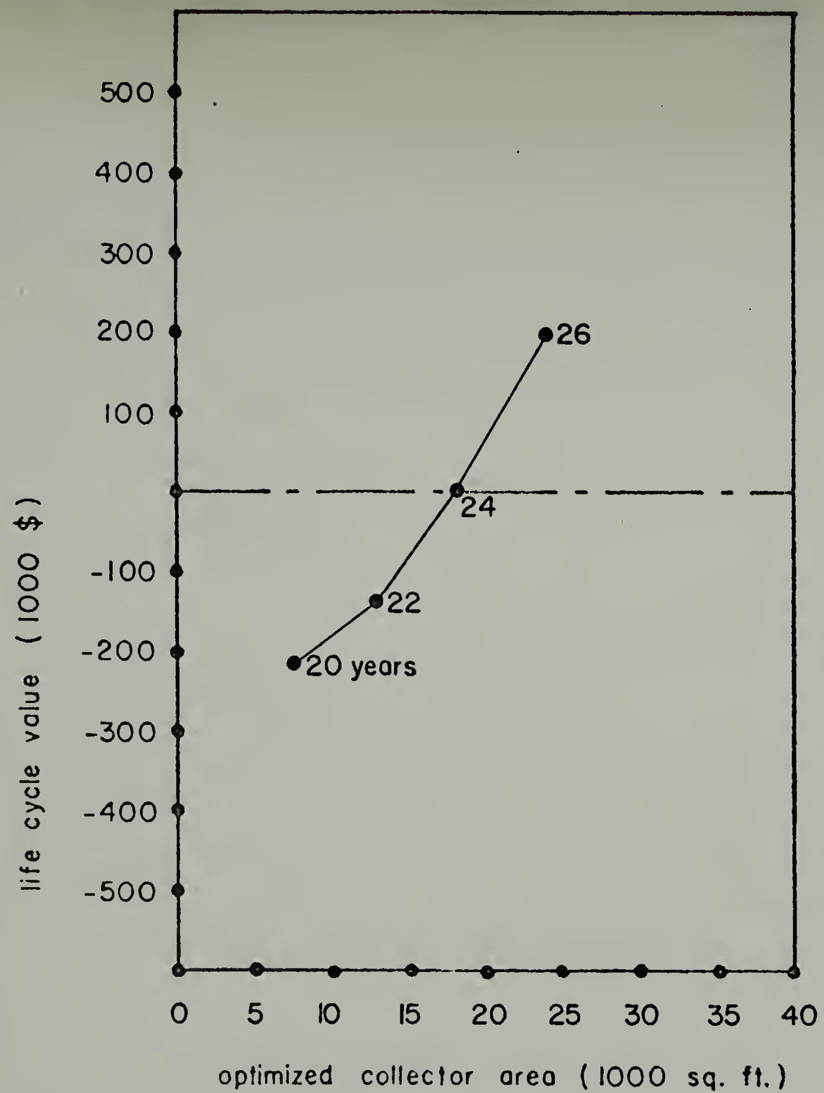
life cycle value vs. optimized collector area



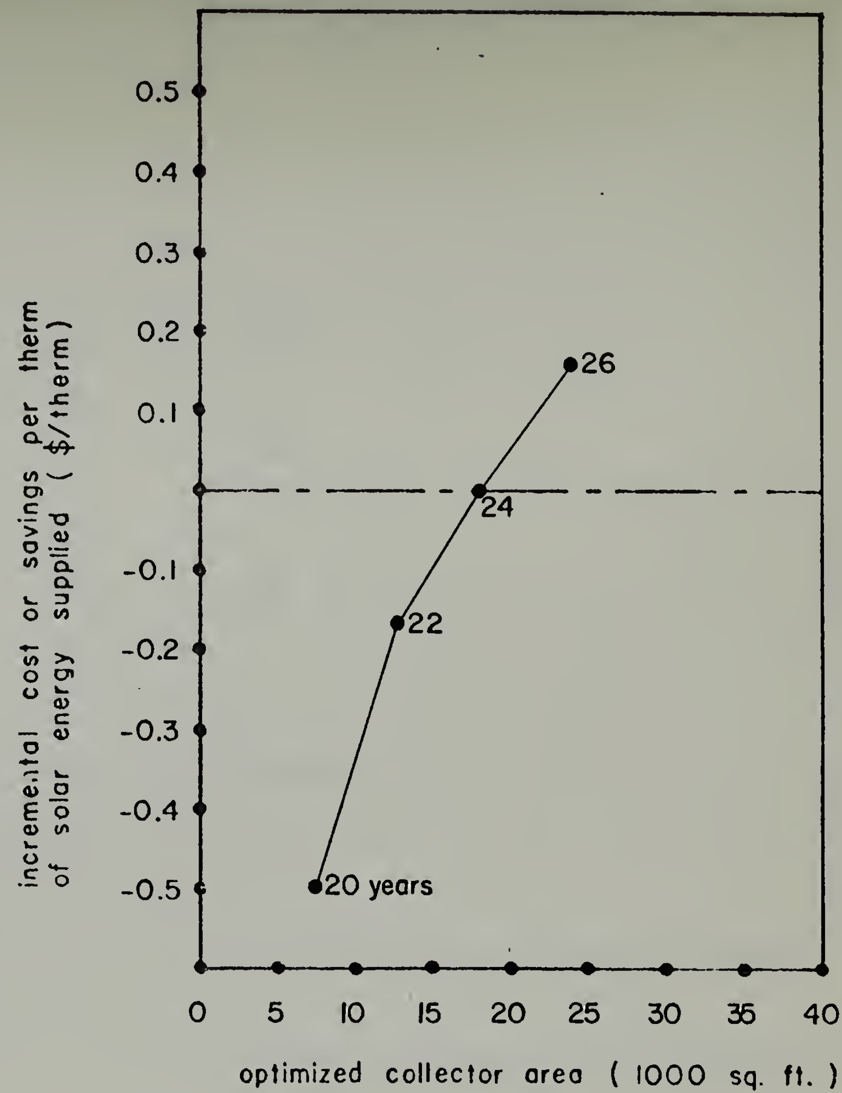
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport — solar feasibility study

fig. 3.2.35 space- pier F (installed cost = $ 807,060)



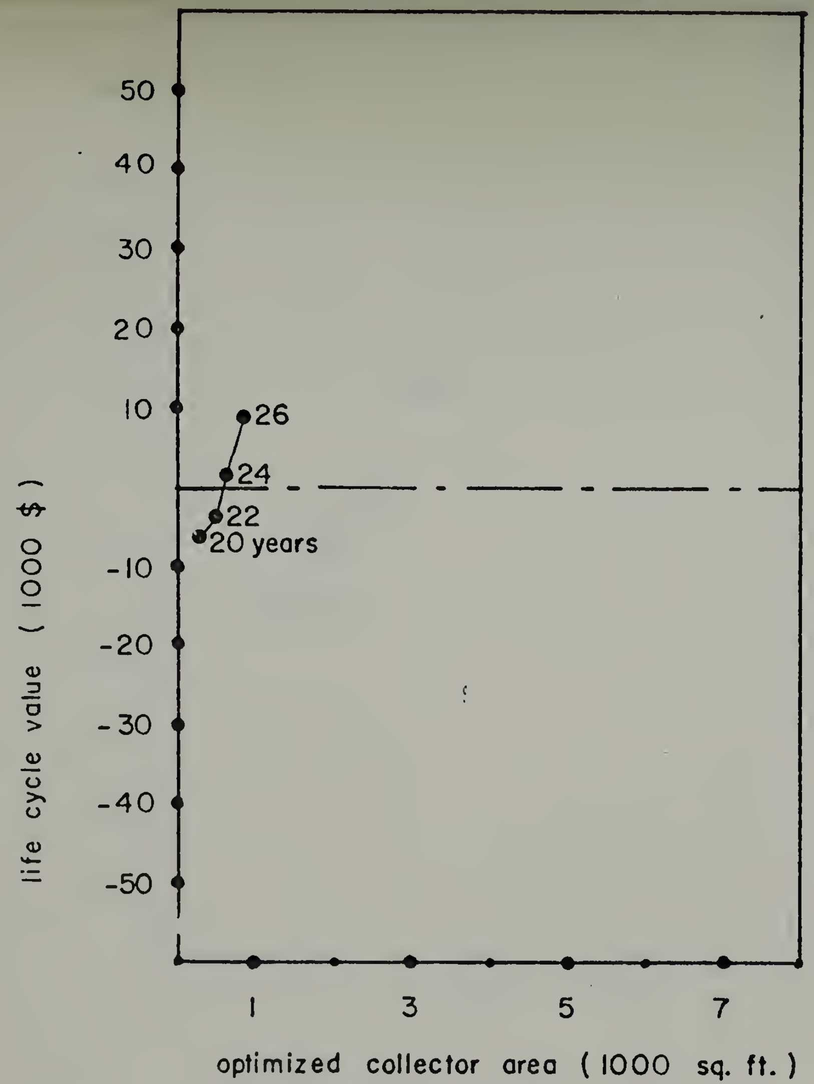
life cycle value vs. optimized collector area



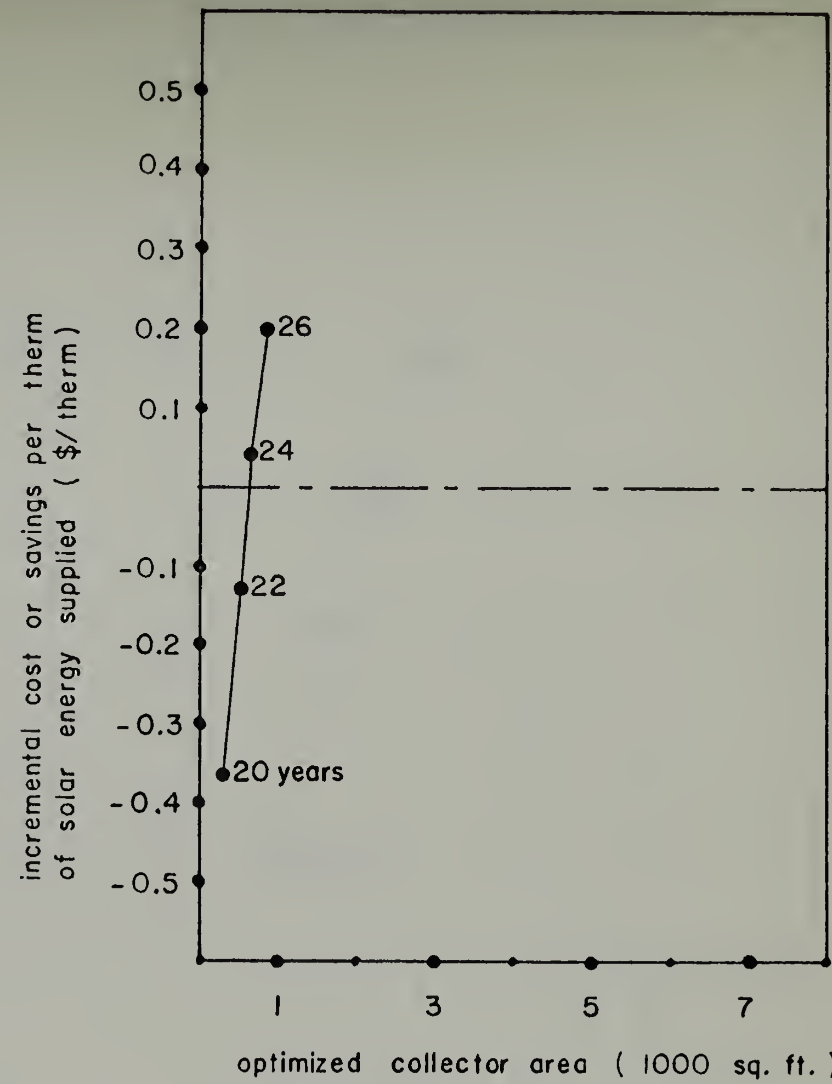
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport solar feasibility study

fig. 3.2.36 DHW & space- pier F (installed cost = $ 860,590)



life cycle value vs. optimized collector area



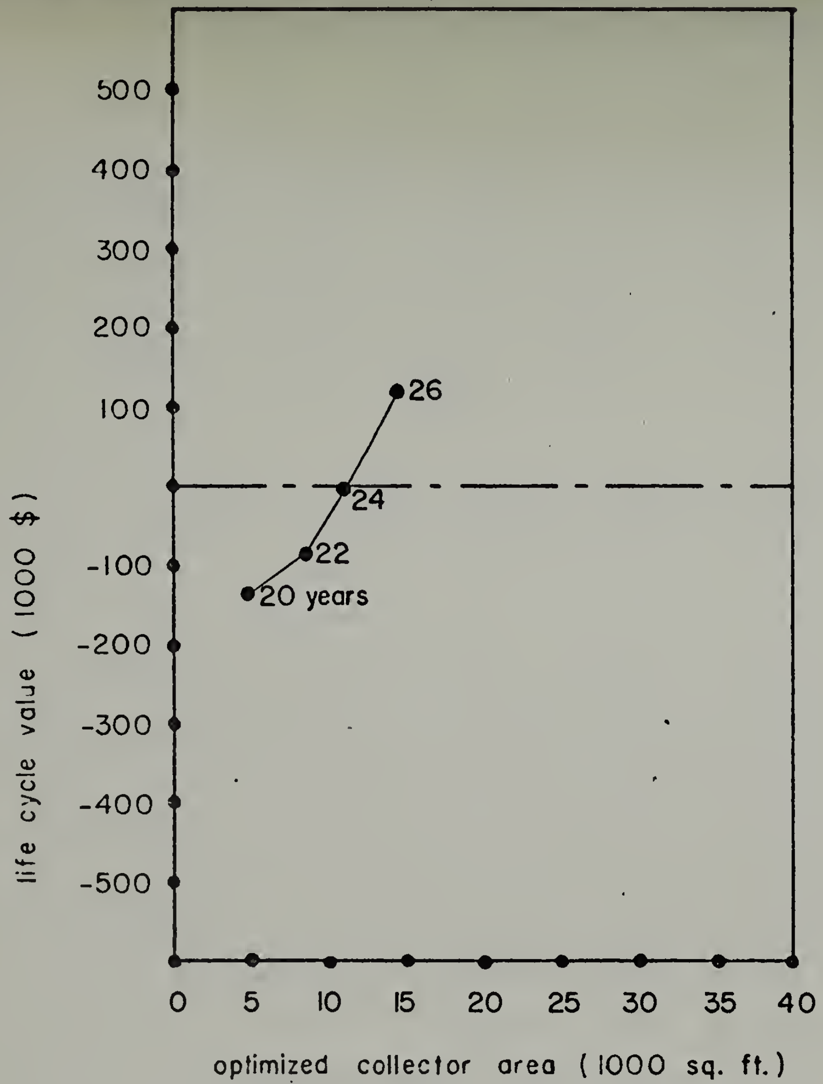
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport

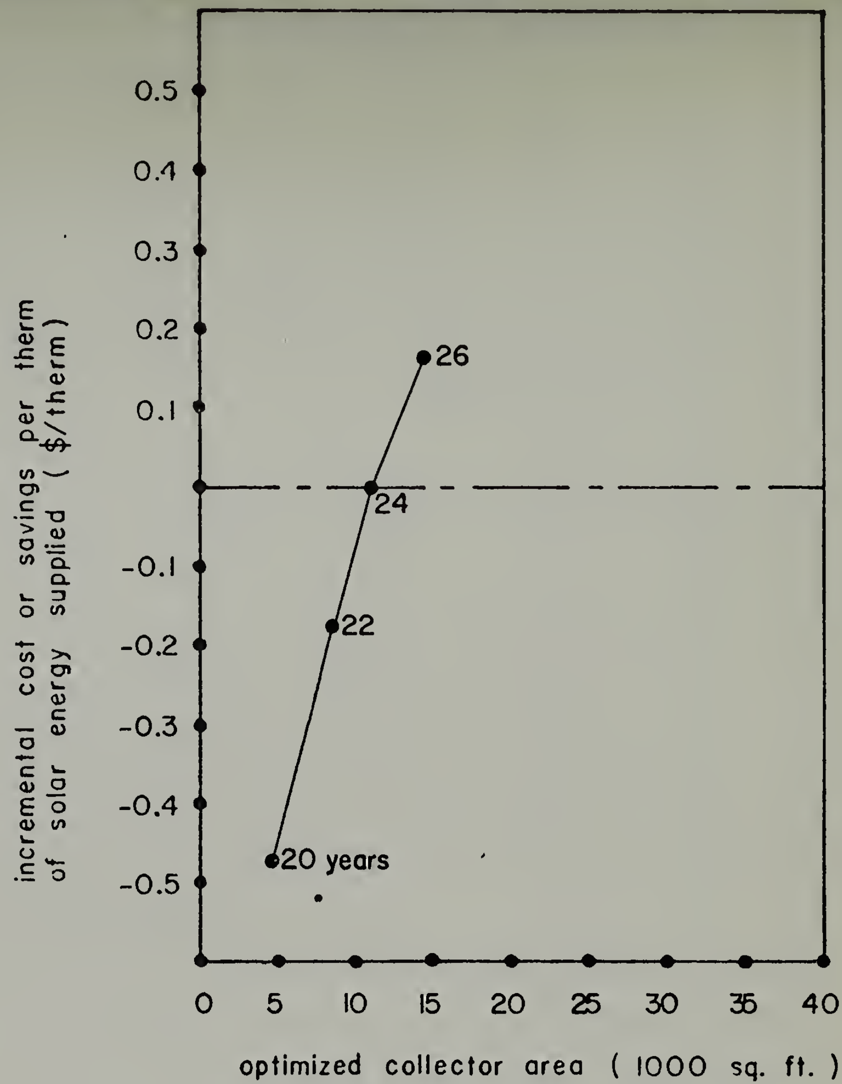
solar feasibility study

fig. 3.2.37

DHW- rotunda A (installed cost = $ 22,320)



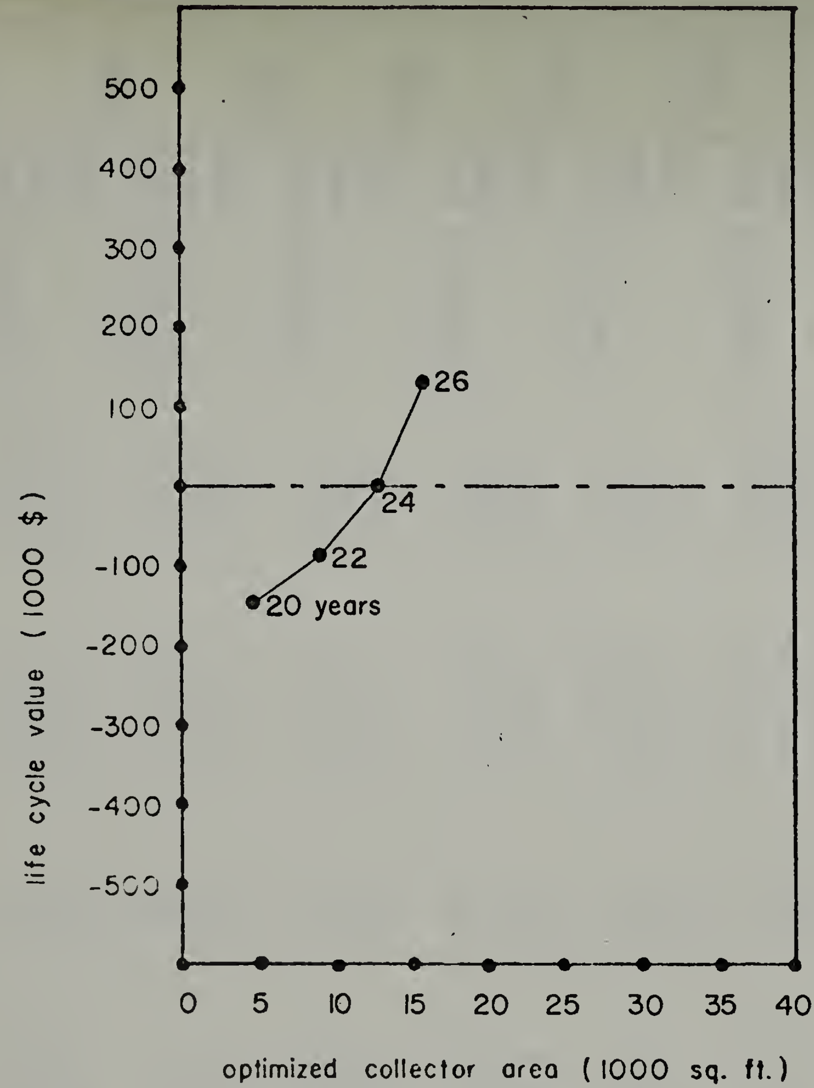
life cycle value vs. optimized collector area



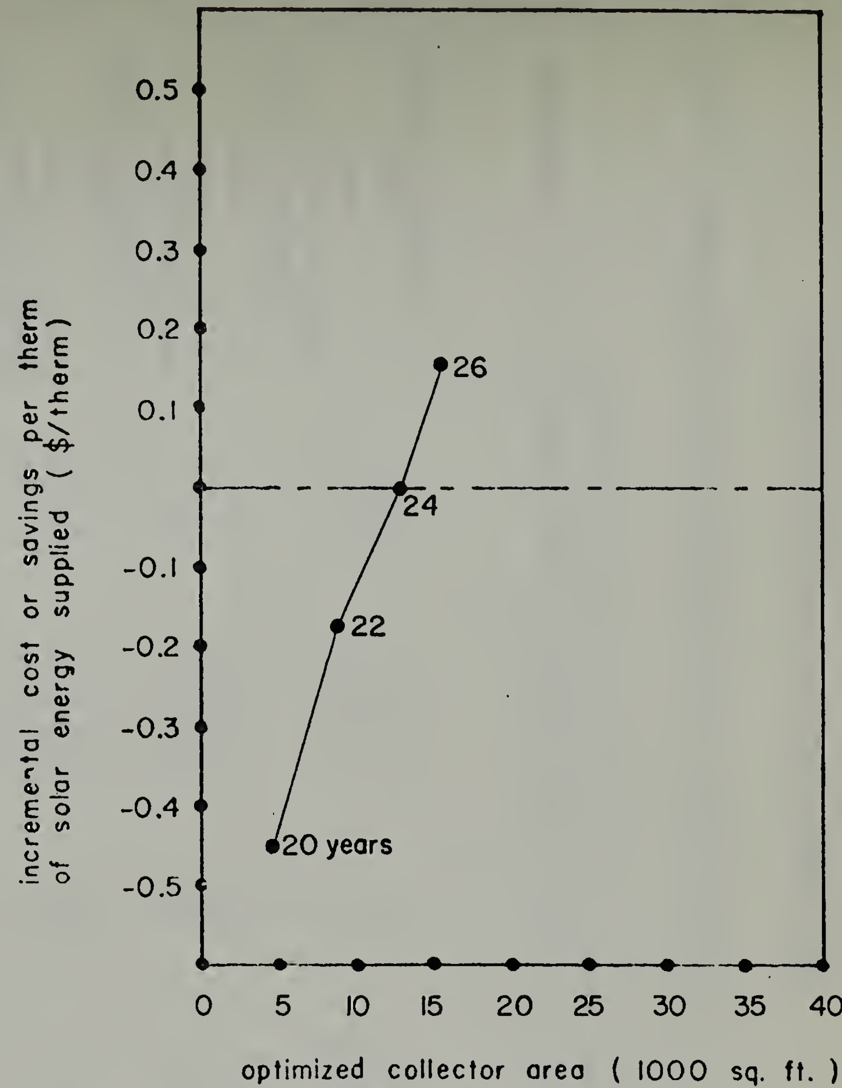
incremental value of solar energy supplied vs. optimized collector area

san francisco international airport — solar feasibility study

fig. 3.2.38 space-rotunda A (installed cost = $ 528,360)



life cycle value vs. optimized collector area



incremental value of solar energy supplied vs. optimized collector area

fig. 3.2.39 DHW & space- rotunda A (installed cost = $ 565,530)

Table 3.2.3

Solar System Size, Performance and Cost

(DHW = domestic hot water heating; Space = space heating.)

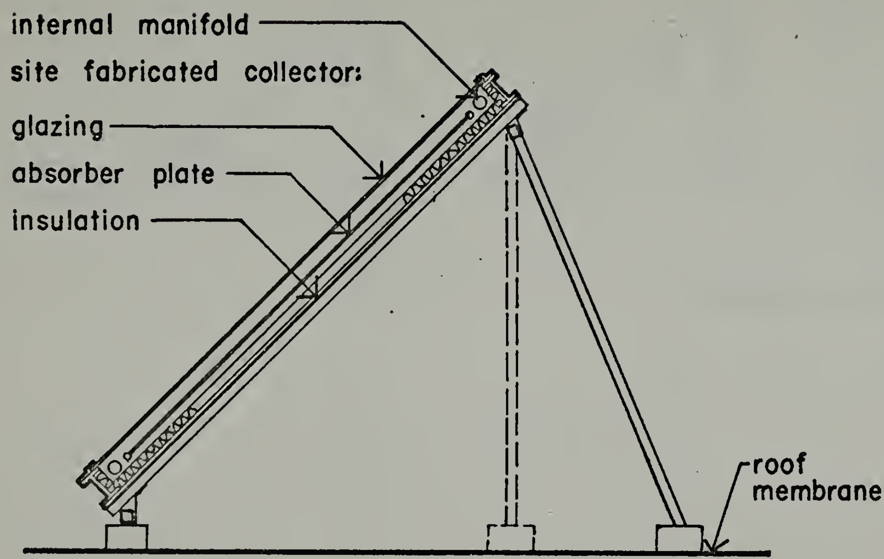
Location	Collector Area (square feet)	Energy Saved (therms/year)	Per Cent Solar	Storage Capacity (gallons)	Initial Cost ($1,000)
South Terminal					
DHW	1,898	5,600	43	3,416	78.19
Space	20,523	56,000	32	36,941	942.75
DHW and Space	23,841	65,300	34	42,913	1,078.47
Central Terminal					
DHW	3,470	10,300	43	6,246	144.81
Space	11,409	31,200	32	20,536	523.37
DHW and Space	17,259	47,400	39	31,066	760.37
North Terminal					
DHW	2,038	6,100	43	3,558	87.53
Space	28,000	77,000	32	50,400	1,296.67
DHW and Space	31,809	86,900	34	57,256	1,442.83
Piers H and I					
DHW	2,859	8,500	43	5,146	117.35
Space	14,628	39,900	32	26,330	671.92
DHW and Space	19,530	53,500	37	35,154	871.01
Pier B					
DHW	661	2,000	43	1,189	29.45
Space	4,441	12,100	32	7,993	204.05
DHW and Space	5,585	15,300	36	10,053	252.80
Pier C					
DHW	1,276	3,800	43	2,296	54.05
Space	4,441	12,100	32	7,993	204.05
DHW and Space	6,598	18,100	38	11,876	293.31
Pier D					
DHW	773	2,300	43	1,391	33.94
Space	4,441	12,100	32	7,993	204.05
DHW and Space	5,773	15,800	36	10,391	260.31
Pier E					
DHW	1,160	3,400	43	2,088	49.41
Space	4,234	11,600	32	7,621	194.35
DHW and Space	6,198	17,000	38	11,156	275.93
Pier F					
DHW	714	2,100	43	1,285	31.58
Space	17,569	47,900	32	31,624	807.06
DHW and Space	18,832	51,400	33	33,897	860.59
Rotunda A					
DHW	483	1,400	43	869	22.32
Space	11,502	31,400	32	20,703	528.36
DHW and Space	12,356	33,800	33	22,240	565.53

i. <u>Collector and Storage Locations</u>. Collectors may be located on any of the roofs. An example of how they could be mounted is given in Figure 3.2.40. Another possibility is to build a lightweight frame structure over the garage to support the collectors (see Figure 3.2.41).

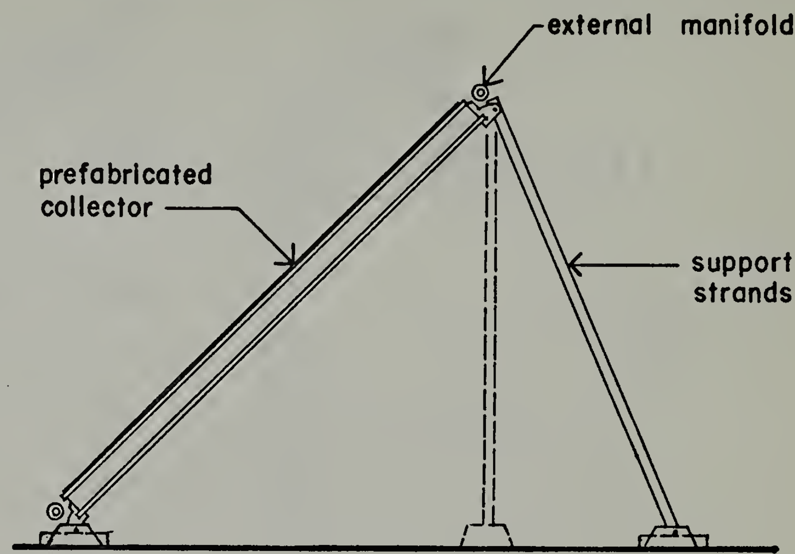
There is ample room to locate the optimized collector areas. A summary of optimized system sizes is given in Table 3.2.3. Potential collector locations at existing facilities are illustrated in Figure 3.2.42, with locations after the modernization and replacement phase in Figure 3.2.43.

Several options are open for storage tank locations: in mechanical rooms; above ground in the parking garage; underground outside piers; and above ground in buildings.

It is important that collectors and storage be located as near to each other and the load as possible. Unlike the existing heating loops, solar systems must operate on low-temperature differentials. To transfer the necessary heat requires a large volume of water. Pipe sizes will be large and significant cost savings can be realized if runs are kept to a minimum.

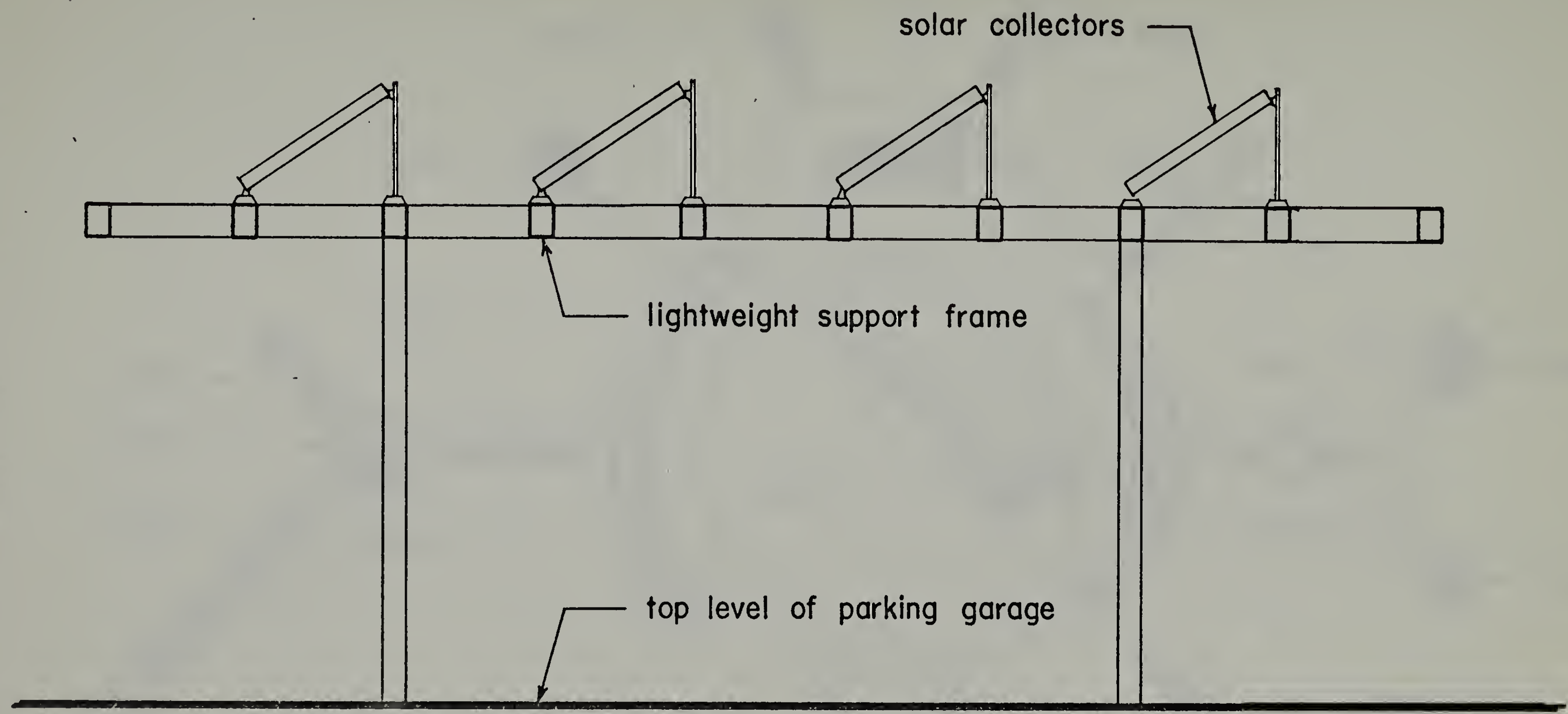


site fabricated collectors



prefabricated collectors

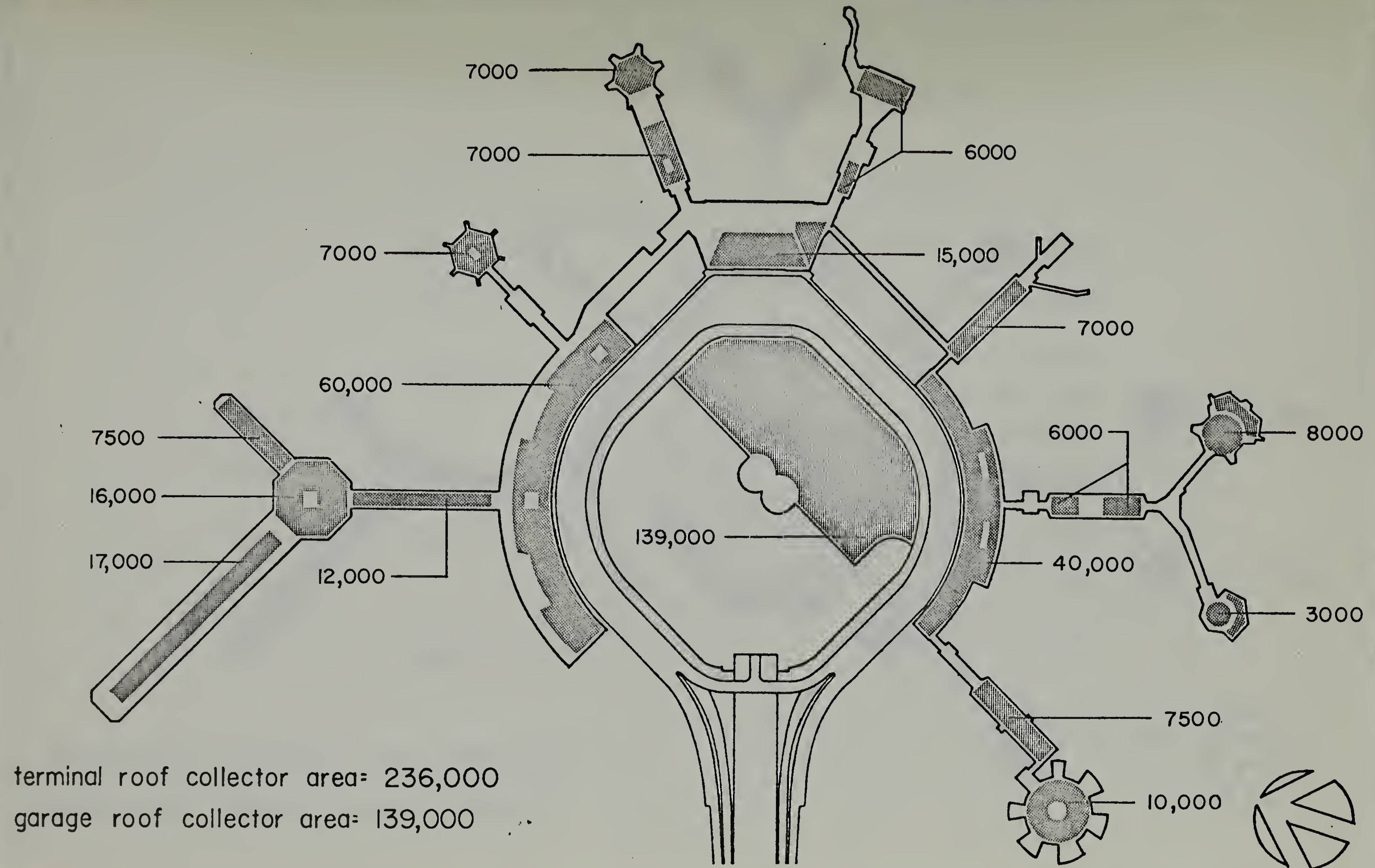
fig. 3.2.40 rooftop collector support structures



san francisco international airport

solar feasibility study

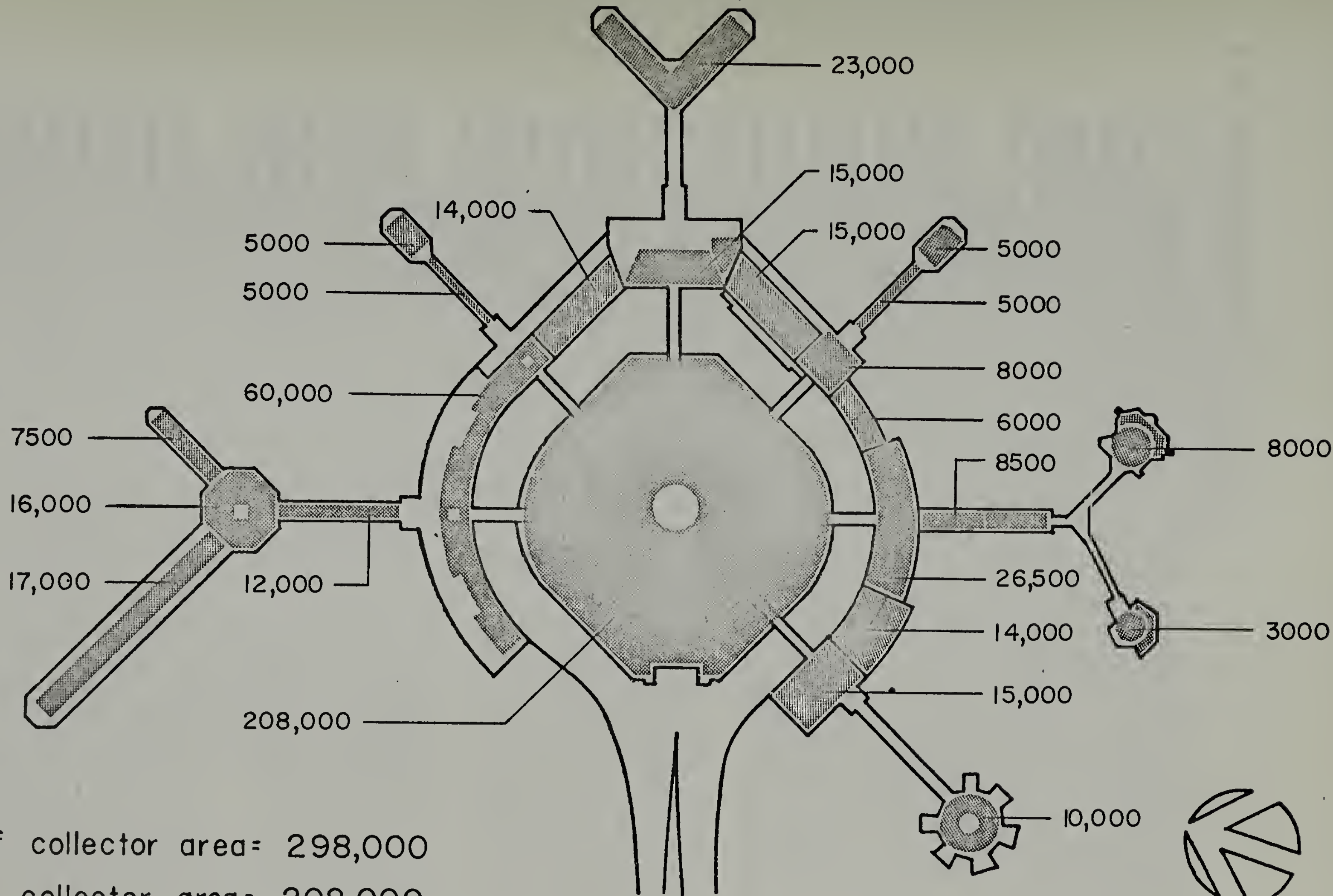
fig. 3.2.41 garage collector support structure



san francisco international airport

solar feasibility study

fig. 3.2.42 possible collector locations- with available collector area (square feet)



terminal roof collector area= 298,000

garage roof collector area= 208,000

san francisco international airport

solar feasibility study

fig. 3.2.43 possible future collector locations- with available collector area (sq. feet)

3.3 Developing Solar Technologies

a. Solar-assisted Central Boiler. A portion of the energy consumed by the boiler can be displaced by utilizing high-temperature concentrating solar collectors which would feed directly into the boiler at the central plant. Heat from the central boiler is then used for space heating and domestic hot water heating via the primary and secondary loops.

Interfacing for this system would be relatively simple because the solar collectors would tie in to the back-up system at only one point, as opposed to the multiple tie-ins required when using flat plate collectors. However, the temperatures required for this system are very high. The design temperature for the primary heating loop is 400°F. for supply and 250°F. for return. This means the supply water to the collectors would always be 250°F. or greater. Figure 3.3.1 illustrates this sytem.

b. Solar Absorption Air Conditioning. Absorption cooling makes use of the evaporation of a fluid refrigerant in order to remove heat from the air being cooled. The evaporated refrigerant is then absorbed in a second fluid, called the absorbent. Heat is applied to the resulting solution to distill the refrigerant, which is then returned to the evaporating coils. The absorbent, having a higher boiling point, remains a liquid and returns to the absorber.

The heat in the regeneration stage, which distills the refrigerant off, may be supplied by solar collectors. Cooling may be accomplished with firing water temperatures as low as 160°F.; however, delivered capacity of a given unit will increase as the water temperature increases to around 300°F. Therefore, medium temperature (150-300°F.) concentrating collectors will probably be the most applicable.

Figure 3.3.2 shows a typical solar absorption cooling configuration whereby the heat from the solar collectors may power the absorption chiller in the cooling mode, or may feed a heat exchanger in the heating mode. The absorption chiller may be used to provide a cooling effect directly or to pre-cool water for an existing compressor chiller. This (absorption air conditioning) system is commonly used for experimental or demonstration purposes; however, it is not generally cost-effective due to a low (less than 1.0) coefficient of performance, high cost, and maintenance problems.

c. Solar Heat Engines. Another method of cooling utilizes solar heat to power a Rankine cycle turbine, or other heat engine, which may be used to directly drive a compression chiller. In this configuration the chiller's coefficient of performance will be high. However, unless the heat engine is supplied with high temperatures, its efficiency will be low, resulting in a low overall coefficient of performance. The use of high-temperature concentrating collectors should maintain an acceptable level of efficiency. This system is optimized further if the turbine or heat engine is used to generate electricity as well as to drive the compressor. Such a system is depicted schematically in Figure 3.3.3.

d. Total Energy Systems. The next level of overall system efficiency can be obtained through the utilization of a total energy system, as shown in Figure 3.3.4. This design uses the heat from high temperature concentrating collectors to drive a heat engine as in the above system. The engine is then used to drive either an electrical generator or a compression chiller. The "waste" heat from the heat engine is then used to either drive an absorption chiller or to feed the secondary space heating loops. The "waste" heat from the compressor or absorption chillers can also be used to provide domestic water heating. This approach is in the developmental stage and will require extensive design and engineering for each system application.

Systems which provide two or more functions are the most likely to become economically attractive, especially where subsystems can be cascaded (e.g., using "waste" heat from a compressor to provide space or water heating). In addition, multifunction systems are used a greater portion of the year allowing for maximum utilization of the solar system.

e. Photovoltaic Cells. Solar radiation may be used to produce electricity in several ways. As described earlier, water heated by the sun may be used to drive a thermal engine. Alternatively, the sun's heat may be concentrated by a field of mirrors on a central receiving tower and used to create steam to drive a turbine. Electricity can also be produced directly through the utilization of photovoltaic cells. All solar electric production methods require a large amount of space to produce the amount of electricity necessary to meet the projected demand.

Photovoltaic cells are semiconductor devices. The most common type is made from silicon which is reduced from ordinary sand. (Research is being done using other materials; however, silicon cells are by far the most easily accessible.) Purified silicon crystal is mixed with a small amount of some impurity such as arsenic, boron or phosphorus and thereby changed from a poor electrical conductor into a semiconductor P-N junction, and then sliced to a thickness between .010" and .012". When a sufficient amount of light strikes the cell, each unit of light (photon) pushes an electron out of orbit and across the junction causing an electrical current to flow. The output of the solar cells is DC electricity. An invertor must be utilized to provide an alternating current.

In order to protect the surface of the cells from the elements, the arrays are enclosed. The cover plate of the enclosure is usually glass.

The output of photovoltaic cells is rates in terms of peak power which is defined as the amount of power generated in direct sunlight in the middle of a bright day at 77^{o}F. The ratio between peak power and average (continuous) power is about five to one. Hence, an array of cells designed to meet a one-watt load would need to have a five-peak-watt capacity, assuming adequate battery storage. Concentrators may be used to decrease the area needed. However, concentrators also produce higher temperatures which result in lower operating efficiencies. A water coolant may be circulated to transfer this heat for use in water or space heating.

<u>Present economics of direct solar/electric conversion.</u>*

A solar cell system with 10 per cent overall efficiency will deliver approximately 11.5KWH per year per square foot. Assuming a cost of $17 per peak-watt, the system cost will be $124 per square foot or $10.80 for a system that will deliver one KWH per year.

The airport terminal complex now uses approximately 64 million KWH per year. Once the North Terminal and piers are opened the use is estimated to rise about 200 million KWH per year. As the existing facilities are improved, the elctric demand is expected to go over 300 million KWH per year in the 1980's.

Assuming a solar system were designed to provide 25 per cent of the current load (16 million KWH per year), the cost of the installation would be $172 million. Currently, the cost of commercial electricity is about $500,000 per year to supply the same energy. The area of this collector would be approximately 1.5 million square feet which is three times the area of the airport roofs.

*Cost and performance estimates based on "Solar Cells: State of the Art," by David Morris, <u>Solar Age</u>, April 1976.

Space limitations on solar cell arrays will mandate that only a small portion of the load may be met. Therefore, storage of electricity will be contraindicated, since all power produced by the solar cells will be used immediately.

Future price reductions. The U. S. Energy Research and Development Administration's goal is to reduce the cost of solar cells to $0.50 per peak-watt by 1985.

Automation. At present, production of solar cells is accomplished almost totally by hand. However, as the demand for solar cells increases, manufacturers will be able to justify automation of the process. The production of solar cells, as with any semiconductor devices, is easily translated to automation. As labor accounts for a large portion of the total costs, automation can be expected to reduce the cost of solar cells dramatically.

Silicon. The cost of the silicon comprises an appreciable portion of the total cost of the solar cells. This cost can and will be reduced as solar cell manufacturers buy in larger quantities. In addition, solar cells have recently been produced with silicon of reduced purity maintaining acceptable efficiency. The cost of silicon varies directly with the purity.

Other materials. Research on the use of materials other than silicon shows promise of resulting in solar cells of low cost and useable efficiency. These materials include gallium arsenide, copper sulfide and cadmium sulfide.

Recommendations. In light of the above-mentioned cost reductions expected in the near future, the photovoltaic production of electricity at the airport should be deferred. A system which holds promise of cost-effectiveness in the future is a hybrid photovoltaic/thermal configuration whereby the heat created by concentrators on photovoltaic arrays would be collected by a coolant and used for space or water heating.

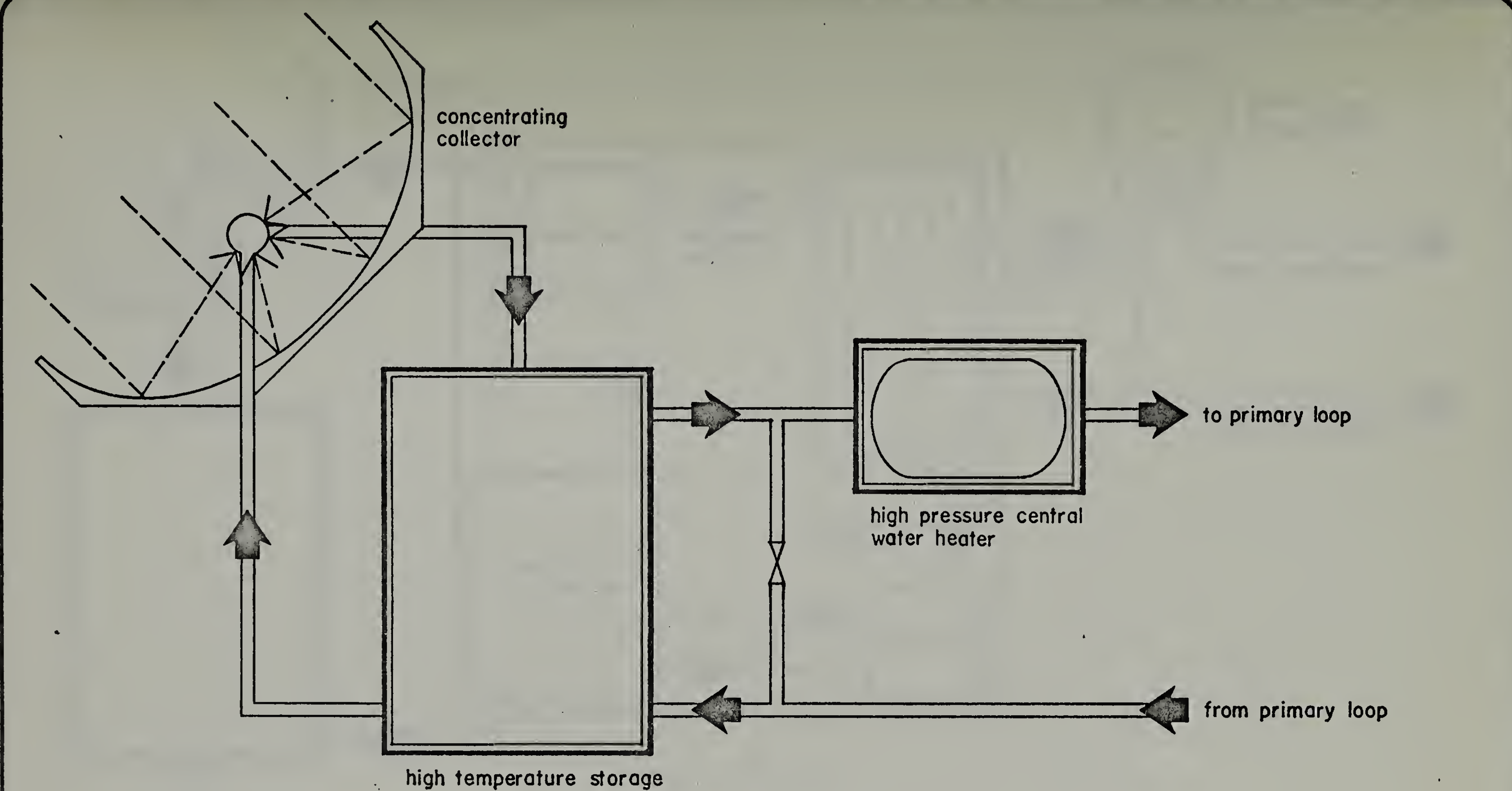


fig. 3.3.1 solar interface with central heating plant

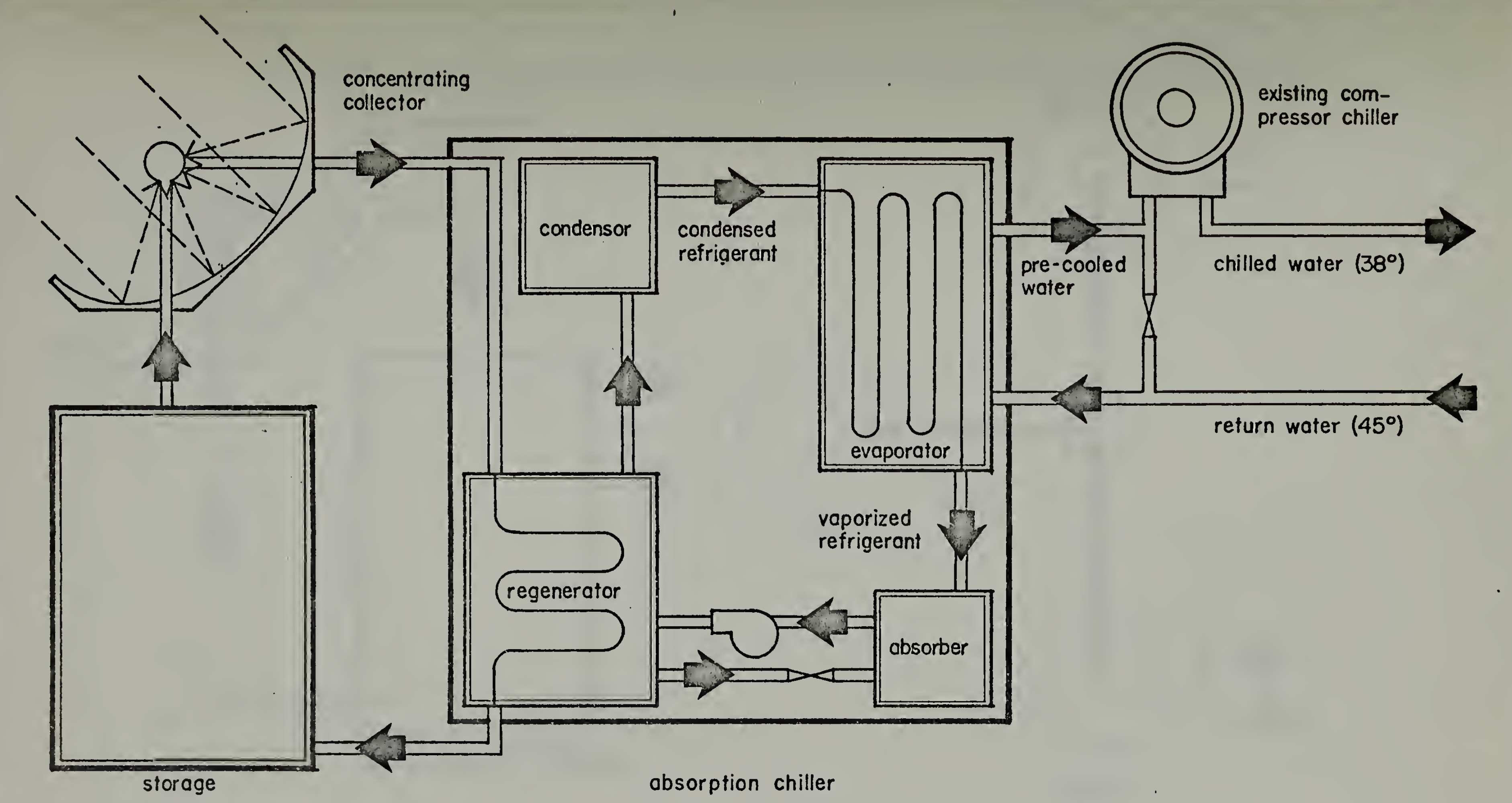


fig. 3.3.2 solar interface with compressor chiller

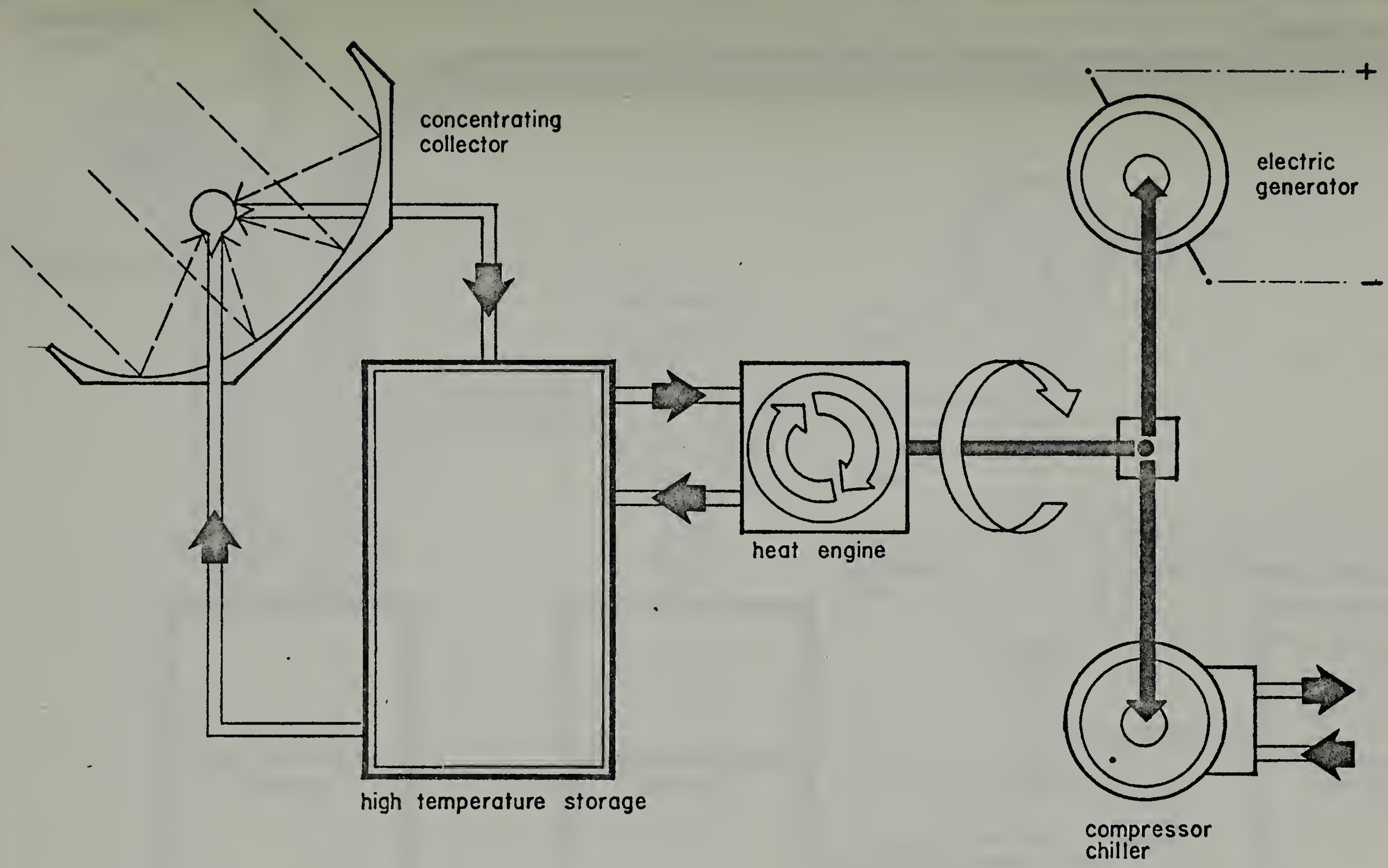


fig. 3.3.3 solar heat engine

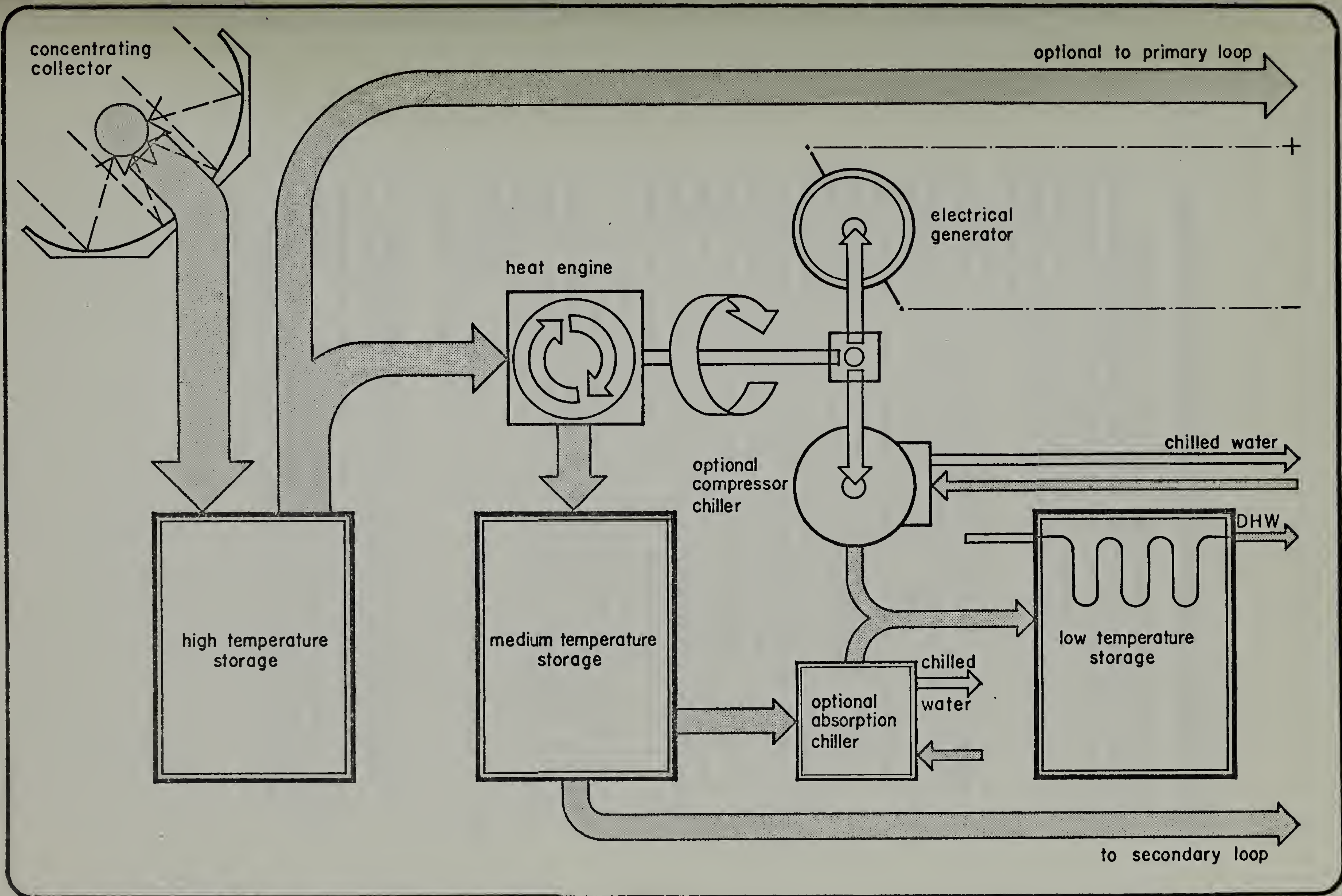


fig. 3.3.4 total energy system

3.4 Special Requirements of the Federal Aviation Administration

a. Visual Glare. There is a potential glare problem with covering the terminal and pier roofs at the airport with solar collectors. The air traffic controllers situated in the new control tower could be subjected to heavy eye strain and possible disabling glare reflecting off the glass covered solar collectors.

A study of the direction of reflections off a collector tilted 40° up from the horizontal was done. The minimum altitude angle of the reflection happens in June at 12 noon. This angle is 25° above horizontal. Next investigated was the geometric relationship between the terminal and pier roofs and the control tower. The largest angle off the horizontal of any direct line from a potential collector site to the control tower is 13°. This occurs between the front edge of the North Terminal roof and the control tower. Since the reflection altitude angle never goes below 25°, the air traffic controllers will not see any reflection. However, collectors placed on a structure over the parking garage north of an east-west axis drawn through the control tower could cause reflections into the control tower unless they are screened out by the control tower itself.

To further ensure that the glare from solar collectors will not create problems at the airport, we recommend the use of specially-treated, non-reflective glazing. This is often accomplished by texturing glass to diffuse the reflected glare.

The FAA will want to judge on this matter before a solar system is installed.

b. Radar Interference. The Instrument Landing Systems are located at the end of the runways. Any large metal construction near the runway could interfere with its operation. Installing copper or aluminum collectors on the terminal and pier roofs could therefore cause interference.

The FAA will want to judge on this matter also before a solar system is installed.

SECTION 4

PASSIVE SOLAR ENERGY APPLICATIONS

4. Passive Solar Energy Applications

4.1 Definition

Any design strategy or building technique that enhances, prolongs, transforms or stores for later use the beneficial effects of the sun, or conversely avoids the undesired effects, is an application of solar energy. Those systems known as passive systems involve a specific design concept: solar energy is collected, stored, distributed or controlled by the building itself.

Elements of building design used to form effective passive systems include building orientation and shape, insulation techniques, choice of structural materials for their thermal properties, sizes and location of glass areas, and window shading techniques. Unlike conventional systems or mechanical solar systems, a passive solar system makes its contribution to a building's energy needs with no expenditure of non-renewable energy sources.

Energy conservation techniques and passive solar energy applications are often difficult to distinguish from one another. While both are essential and interdependent elements in any soundly designed solar system, there is a difference in the roles they play. Conservation techniques are concerned primarily with energy control within a building regardless of the source of the energy. Passive solar applications, on the other hand, are specifically involved with utilization and control of the sun's energy. Since effective energy conservation minimizes a building's energy demand, the effectiveness of a given solar energy application is maximized.

Successful design of passive solar applications demands that the building be designed or modified to function as an integrated energy system. Unlike mechanical solar systems, passive techniques do not clearly stimulate a separate definable market or industry. Since they cannot be sold, there are no salespeople, and the incentive to "buy" is left to the building designer or owner.

4.2 The Decline and Rebirth of Climate-adaptive Architecture

Traditional architecture has evolved in a manner consistent with available building materials and technologies. Before the availability of cheap energy, a building had to adapt to its climate if it were to provide the inhabitants with a comfortable interior environment. The Mesa Verde cliff dwellings in Colorado, for example, provided a comfortable habitat even during the hot summer days through climate-adaptive design. With the advent of cheap energy, thermal comfort was no more dependent upon climate-adaptive techniques; mechanical systems, fueled by cheap energy, could economically provide comfort, even for energy-inefficient designs.

Recent fuel shortages and rapidly increasing utility rates, however, are causing a renewed interest in climate-adaptive architecture. Passive solar energy is climate-adaptive; without mechanical assistance (and the fuel needed to run these systems), a passive solar system provides thermal comfort through adaptation to the solar phenomena of its site.

4.3 Modeling

Analyzing energy use at the airport, owing to the scale and range of activities that take place there, is a highly complex task, yet essential in forming the basis of an integrated energy system. Two techniques which assist in providing this analysis are thermography and computer modeling. Thermography serves to evaluate the effectiveness of existing thermal insulation, exposing both construction and design flaws. Computer modeling establishes overall energy use patterns, enabling the design of an optimum energy system.

a. Thermography. The use of infra-red photography offers a method of analyzing thermal characteristics of buildings at the airport. The technique, called thermography, is new but has been used with success and is quite sophisticated. An infra-red scanning camera is used to produce images in which a range of calibrated shadings shows equivalent temperature distributions. Analysis converts this information to show conductive, convective and radiant heat transfer, both in qualitative and quantitative terms.

Thermography is used to study existing buildings for energy-wasting defects which can then be remedied. Buildings can be photographed from both inside and outside. Problems such as inadequate or missing insulation, infiltration and high conductive loss or gain can be quickly and accurately identified. Qualitatively, exterior photography shows warm surfaces in light tones, cool surfaces in dark tones; this is reverse for interior photography. A series of photographs showing, for example, all interior surfaces of a room will pinpoint locations of excessive loss or gain. After corrective measures have been taken, review photography will show the effectiveness of these measures. Causes of heat transfer due to reasons other than construction deficiencies can also be identified, such as localized air turbulence creating high convective losses at a particular wall surface.

Interior thermography tends to produce more refined results than exterior because ambient conditions are controlled. Exterior and aerial photography are affected by variable weather conditions—wind, clouds, etc.—and influences from surrounding buildings—reflections, etc. Aerial photography has the advantages of low cost per unit of area covered, rapid data collection and collection during generally constant overall weather conditions. However,

there is a lack of detail, only views of upper building surfaces are shown, and there are some conflicts in the type of information the camera receives. At the airport there may also be problems with the regular heavy flow of air traffic. Ground exterior photography is similarly suited for rough measurement only, due to variable weather.

At the airport an interior and ground exterior thermographic review would be beneficial in two ways. First, construction defects and special problems relating to thermal losses and gains in existing buildings could be accurately spotted. Second, the general thermal characteristics of existing buildings could be studied, in their context, for lessons both good and bad which may be valuable to the design of future additions.

A case study could be made using Piers H and I. This would establish the methodology for the photography of the entire airport. These piers should be representative of most conditions which future construction must address. Thermal qualities of typical wall, roof and even floor construction could be evaluated, and the information applied to adjust the design of new piers before they are built, rather than waiting until after construction to make more expensive and less effective changes.

b. Computer Modeling. Computer programs are available that simulate the thermal performance of buildings, describing the functioning of various systems on an hour-to-hour basis in response to external conditions and interior use patterns. They can analyze and quantify the amount of heat transferred through a building's skin as outside temperatures change, as patterns of sun and shadows change, and as the internal heat inputs and demands vary in response to different occupancy patterns, lights and motors, ventilation provisions, and machinery loads.

These programs can predict with considerable accuracy how much fuel oil or gas will be needed and how many KWH of electricity will be consumed and the total energy-use profile for the building can be determined. As various building components are changed—e.g., double-glazing instead of single-glazing, a few degrees lower heating requirements, a 20 per cent reduction in lighting—the program will show how each of the systems responds to the change. For example, less lighting will also affect the air conditioning requirement, reducing it because of less heat input, but raising fuel use in the winter for the same reason.

Through the careful use of such programs, it is possible to approach an optimization of the mechanical performance of the building under study, which is always assumed to be a sealed building (except for some heat gained or lost through cracks in the wall and at openings as a result of infiltration). The effect of changing the thermal characteristics of the wall, the amount of glazing, the building's orientation, the gross pattern of turning lights on or off, the number of people, and the time of occupancy can be measured.

Necessarily the program cannot measure choices that are not presented to it. The building designer's decisions determine the information fed to the machine. The programs can be extremely useful as analytical tools if their three basic inadequacies are recognized.

First, the programs can in no way simulate the performance of highly differentiated and unpredictable ways a building and its occupants perform with something as simple as openable windows. One cannot program the number of windows open at any one time, the amounts of opening, the shutting of windows when there are gusts of wind, the sudden shifts of wind from one facade to another, the different between the windward and leeward sides of the building, the cooling effect of air in motion, or the sound of wind in the trees. As a result, this whole option is eliminated when one turns to the computer for evaluation of alternatives.

Second, even though the computer can deal with a vast number of calculations and statistics, these are very fragmentary in comparison with the number of variables that occur in our everyday lives. It has been observed that major energy savings are possible when the application of energy to tasks closely follows the energy-demand profiles of the tasks themselves. If light is on at a desk only when that desk is used for a task requiring light, if cooling is provided only when a space is in use during a time that requires cooling and only to the extent required by its occupancy pattern, if ventilation closely follows the metabolic requirements of a space's occupants and their activities, or if an escalator operates only when someone needs to use it, the resulting energy-use pattern will be minimal. There is no way the computer can cope with this diversity of choices except by the crudest average guesses, and averages are very different from the figures that determine them.

Third, there is no way for the computer to tell its user to draw the right conclusions from the printout.

Once the capabilities and limitations of computer simulation of building energy use are realized, useful and informative comparisons can be made and energy can be saved.

4.4 The Application of Passive Solar Energy

Passive solar energy techniques which will be discussed in this section are glazing and building orientation, solar shading and sun controls, thermal insulation and thermal mass, natural ventilation, and natural lighting. Since effective application of passive techniques implies an integrated system, separating and categorizing individual techniques is difficult, resulting in some overlap within the ensuing presentation.

4.5 Glazing and Building Orientation

As a key architectural design element, glazing has a strong influence on the form of a building and its resultant energy use. Glazing can serve as a prominent feature of the facade, an effective source for interior day lighting, and a visual and psychological benefit to the building's occupants. Glazing also has a significant impact on a building's energy use; its thermal properties make it extremely vulnerable to heat gains and losses. Thus, to affect an energy-efficient building, special attention must be paid to glazing design. A number of approaches to glazing design and treatment have been analyzed in this study to show the importance of orientation and the variety of opportunities for energy savings.

a. The window as a solar collector. If oriented properly, glazed areas can serve as effective solar collectors. When the outside temperature is lower than that of the inside, all orientations will lose heat through the glazing to the outside through radiative, conductive and convective means. However, some orientations gain far more heat than they lose through incident solar radiation, as shown in Tables 4.5.1 and 4.5.2. Figure 4.5.1 graphs heat gain data from these tables for the various orientations throughout the year for both existing glazing conditions and for limited glazing (as described in Section 4.5.b).

A south-facing window may be the ideal solar collector. In the winter, when heat gain is desired, this orientation receives the most heat from the low winter sun. During summer, when heat gain must be avoided, less sunlight will be incident on south-facing glazing than either east or west orientations. The small amount of radiation received in summer can be reduced to even less than that received by north glazing, with the addition of a properly designed overhang. Due to the low angle of the winter sun, the overhang will affect minimally, if at all, the penetration of needed solar gain.

While some east-facing windows can help take the chill off cool mornings, too many can cause overheating during warm periods. As summer heat gain can be a significant problem, west-facing windows should be avoided or shaded to reduce air conditioning loads. Only limited solar heat gain is received from west orientations in winter. North windows provide natural light, but make no solar heat contribution during the heating season.

Any design that takes advantage of the solar radiation incident upon glazed surfaces by transforming it into useful and productive energy is of important value to the airport in terms of energy savings. Similar savings result in avoiding glazing in orientations prone to high summer heat gains or high winter heat losses. In general, north, east and west glazing should be kept to a minimum, while properly shaded south-facing glazing should be encouraged.

b. Reduction of window area (limited glazing). One important consideration and recommendation is that window areas be reduced, as illustrated in Figure 4.7.3. This will be extremely effective in reducing heat gain in the summer along with reducing heat loss in the cooler seasons. Using a limited amount of window area may be economical not only in long-term energy use, but in terms of initial construction costs as well.

c. Double glazing. Insulating glass, like insulated walls, will save energy during the heating season; however, their overall effectiveness may be counter-productive where internal heat gains dominate heat losses and air conditioning is required. Computer modeling is again recommended in order to determine the optimum solution.

4.6 Sun Control and Solar Shading

a. Definition and application. Since glazing is much more vulnerable to solar heat gain than most other building components, proper sun control for glazed areas can be essential in controlling overall building heat gain. A solar shade, one type of sun control, can be described as a device which serves to intercept the rays of the sun, preventing them from entering the interior space of the building. As seen in Figure 4.6.1, the proper application of such a device substantially reduces heat gain. Of a given 100 units of incident solar radiation, different portions of this are transmitted, reflected, reradiated and convected, or absorbed. The left side of the diagram shows that glazing of heat-absorbing glass (similar to the glass in the North Terminal and Piers H and I) allows transmission of 66 per cent of the incident radiation. The introduction of an ideal solar shade, even with the use of regular glass, reduces the total transmitted radiation to only 23 per cent, as illustrated on the right.

Basic solar shade configurations include vertical louvers, horizontal overhangs and a combination of both termed "egg crate" (see Figure 4.6.14). They can be located indoors (e.g., venetian blinds) or outdoors, in fixed or adjustable positions. As size and type of shading devices are dependent on the glazing orientation, a separate analysis must be done for each orientation. The effect of adding solar shading to all windows vulnerable to heat gain would be to reduce solar heat gain (and the corresponding cooling requirement) to 34.8 per cent of the existing condition. Further reduction of heat gain to just 19 per cent of the existing would result from reducing the size of the glass opening (i.e., limited glazing).

b. Methodology. Shading devices have been described for all facade orientations of the airport, as illustrated in Figures 4.6.2 and 4.6.11. The methodology used in designing these shades included determination of the overheated period, correllation of this period to the sun-path diagram, and application of the proper shading mask. Additional criteria used in selecting the devices included architectural design contraints (to provide conformity with the building facade) and consideration of the economics of installation.

The overheated period for conditions at the airport can be defined as the times when the outside temperature is above 65°F. During this period, shading is necessary for glazed surfaces subjected to solar radiation. Temperature data taken at the airport over a five-year period were used to produce the overheated period chart shown in Figure 4.6.12.

By projecting the path that the sun follows on a given day of the year on to a horizontal plane, as shown on the right of Figure 4.6.13, a sun-path diagram is produced. The three sun-paths shown in this figure are for the summer and winter solstices (the extreme paths) and for the fall and spring equinoxes. Shown at left is the sun-path diagram for 36° North latitude, approximately that of the airport. From the sun-path diagram, the relationship between the sun's position in the sky and a given building can be ascertained for any time during the day throughout the year. For example, at 8 a.m. on June 21, the sun is due east at an altitude (i.e., angle above the horizon) of 35°, as marked by the "sun." By plotting the overheated period on to the sun-path diagram, a direct correlation between the times when overheating occurs and the position of the sun is established. The chart does not show overheating due to internal loads, however, which have to be considered separately.

A shading mask shows at which solar angles a given shading device will be providing shade. Each of the three basic types of shading devices forms its own characteristic mask on the sun-path diagram: vertical louvers, a sectional mask; horizontal shades, a segmental mask; and eggcrate devices, a combination of segmental and sectional. Figure 4.6.14 illustrates this.

Generally, a shading device will be effective if it provides a minimum of 50 per cent shading throughout the overheated period. This is achieved if the 50 per cent shading mask covers the entire overheated period of a given orientation . Times when 100 per cent shading occur (referred to in the illustrations as the "critical shade angle") can be determined from sectional drawings of the selected shading device.

In Figure 4.6.3, for example, the overheated period for an orientation of N67.5°W is the portion of the period to the left of the building orientation line. As the sectional character of the overheated period suggests a vertical shading device, a choice of 60° vertical louvers was made (as

illustrated in the horizontal section and accompanying isometric). On June 21, when overheating occurs between 12:30 p.m. and 5:30 p.m., this shading solution provides a minimum of 50 per cent shading almost throughout the overheated period (until 5:00 p.m.) and 100 per cent shading until 3:00 p.m. A well designed shade has an additional characteristic: it allows maximum solar penetration during the colder months when heat gain is desired. While the suggested 60° vertical louvers prevent any solar heat gain during winter months, this orientation receives little useful insolation at this time; the 60° louvers remain a viable solution.

c. Architectural design considerations and recommendations. The effectiveness of a shading device will depend on its relationship to the sun intensity that is intercepted during the overheated period. Placing this definition in the context of the airport, different types of shading devices have been analyzed in terms of effectiveness, architectural design and economics.

A number of shading devices are already in use in the terminals and a few in the piers. Where interior shades, louvers or blinds were located in heavily occupied areas, they were often damaged in some way. Although inexpensive to install, these shading devices are not very effective in blocking solar radiation. Maintenance and appearance of these devices also seems to be a problem.

As shown, heat-absorbing glass is not an effective solar shield. The recommended exterior solar shade has a fundamentally sound method of intercepting solar radiation—before it penetrates the building, with the added effect, if properly designed, of allowing solar radiation penetration during winter months.

One of the better designed buildings in terms of solar shading is the new boarding area B using an egg-crate design. Although the building has limited the solar heat gain, no consideration was made toward proper orientation. Also, there is a problem where the shading devices has been directly attached to the building, because on windless hot days this type of solar shade will conduct heat to the building. Isolating the devices from the building would relieve this problem.

Other considerations in selecting solar shades will be maintenance problems and possible projections into runways; the solutions would be in the hands of the architectural design team.

4.7 Thermal Insulation and Thermal Mass

a. Definition and applications. Materials such as water, concrete and stone have the capability of storing large amounts of heat and are said to have "thermal mass." Less dense materials such as air, plastic foams and wood have poor caiabilities for either storing or transmitting heat and are therefore known as "insulators." In a passive system, these materials are integrated into the structure; materials with thermal mass serve to store heat while insulating materials serve to impede the flow of heat.

b. Thermal insulation. The drawings and specifications of the new North Terminal and Piers H and I call for specific applications of thermal insulation. Full understanding of the role of insulation in a building requires a comprehensive study of interior and exterior heating and cooling loads. For example, most buildings at the airport have a greater internal heat gain than heat loss. Electric lighting, solar heat gain through windows, and occupant load often contribute in producing temperatures above the comfort level. In fact, when the outside air temperature is above approximately 55°F., the air conditioning systems will start cooling the buildings. Under these circumstances, increasing the insulation may be counter-productive, and determination of the optimum insulation thickness would require computer modeling.

Generally, increased insulation will reduce heating loads by holding heat in, and reduce cooling loads by keeping heat out, especially solar loads. Total energy saved and optimum insulation thickness are variables that should be analyzed by computer modeling.

Figures 4.7.1 and 4.7.6 illustrate the potential for increasing insulation in the roof, walls, fascia and soffits. Additional insulation can easily be installed and at a relatively low cost in each of these areas.

c. Thermal mass. Increasing the thermal mass in a building will enable it to dampen or stabilize the effects of both exterior and interior temperature fluctuations that deviate from the design comfort ranges. Effective use of thermal mass as an energy-related design element requires a thorough analysis of all loads, heat gains and losses, and site microclimate on an hour-by-hour annual basis. The airport already incorporates substantial amounts of massive materials (steel and concrete). The optimum placement of additional mass can be analyzed through computer modeling.

4.8 Natural Ventilation

With any structure, proper utilization of ventilation is essential to enable the interior space to fall within the realm of a "comfort zone." The airport, with prior air filtration, could reduce its cooling load still further by introducing outside cool air directly to the interior space. This subject is treated extensively in Section 5, Energy Conservation.

4.9 Natural Lighting

Through architectural design considerations, a substantial amount of sunlight could be used to light interior spaces, thus substantially reducing electrical lighting loads.

The piers and boarding areas provide good opportunities for daylighting since these elements are only one story high. North light roof monitors will provide a daylight factor of 1/3 (glass area/floor area). The daylight factor is the percentage of outside illumination in footcandles that penetrates into the room.

A weather-averaged winter sky supplies 800 footcandles (fc) of illumination outside. Therefore, to achieve 40 fc inside, the daylight factor would have to be five per cent. This means the glass area/floor area ratio will have to be 0.15. Thus, for a pier 60-feet-by-60-feet with a floor area of 3,600 square feet, 540 square feet of north light roof monitor windows equally distributed over the area will supply 40 fc of illumination inside.

Light from the sun is pleasing to the eye owing to its color, and is a comparatively efficient source of illumination, providing 100-120 lumens per watt, as compared to fluorescent light at 70 lumens per way. Natural daylighting will not only save electrical energy used to power artificial lights, but when properly sized, it illuminates a space with the least possible addition to the cooling load of the space.

Table 4.5.1

Window Heat Gain
(Existing)

Assume one section of glass at different orientations.
one 10' glass x one lin. ft. = 10 sq. ft.   3/8" tempered

Orientation of Window	December 21 (Average) Heat Gain BTU/Day	Heat Loss $\Delta T = 15^{\circ}$	Net Heat Gain (+) Heat Loss (-)	June 21 Heat Gain BTU/Day
N 45° E	1,200	4,146	- 2,946	9,010
N 67.5° E	2,280	4,146	- 1,866	10,986
EAST	4,700	4,146	+ 554	11,890
S 67.5° E	7,900	4,146	+ 3,774	11,470
S 45° E	11,480	4,146	+ 7,334	9,730
S 22.5° E	14,810	4,146	+10,664	7,050
SOUTH	16,130	4,146	+11,984	5,750
S 22.5° W	14,810	4,146	+10,664	7,050
S 45° W	11,480	4,146	+ 7,334	9,730
S 67.5° W	7,920	4,146	+ 3,774	11,470
WEST	4,700	4,146	+ 554	11,890
N 67.5° W	2,280	4,146	- 1,866	10,980
N 45° W	1,200	4,146	- 2,946	9,010

Table 4.5.2

Window Heat Gain
Limited Glass

Assume one section of glass where glass area is 4'6" high, and a wall section of 5'6".
Area of glass 4.5 x 1 = 4.5 sq. ft.
Wall - heat gain and heat loss negligible.

Orientation of Window	December 21 (Average) Heat Gain BTU/Day	Heat Loss $\Delta T = 15^{\circ}$	Net Heat Gain (+) Heat Loss (-)	June 21 Heat Gain BTU/Day
N 45° E	540	1,865	- 1,325	4,054
N 67.5° E	1,026	1,865	- 839	4,941
EAST	2,115	1,865	+ 250	5,350
S 67.5° E	3,555	1,865	+ 1,690	5,161
S 45° E	5,166	1,865	+ 3,301	4,378
S 22.5° E	6,664	1,865	+ 4,799	3,172
SOUTH	7,258	1,865	+ 5,393	2,587
S 22.5° W	6,664	1,865	+ 4,799	3,172
S 45° W	5,166	1,865	+ 3,301	4,378
S 67.5° W	3,555	1,865	+ 1,690	5,161
WEST	2,115	1,865	+ 250	5,350
N 67.5° W	1,026	1,865	- 839	4,941
N 45° W	540	1,865	- 1,325	4,054

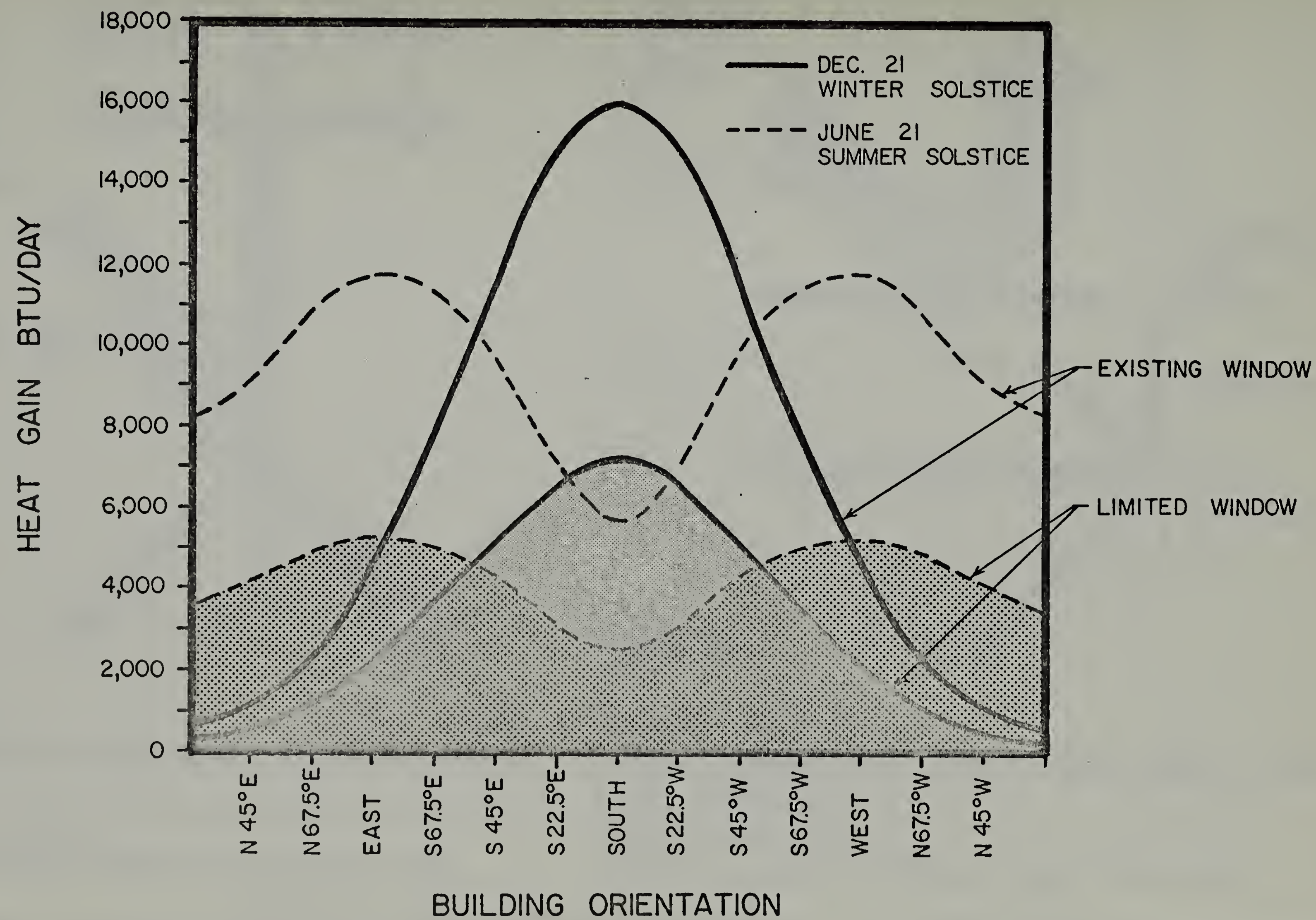
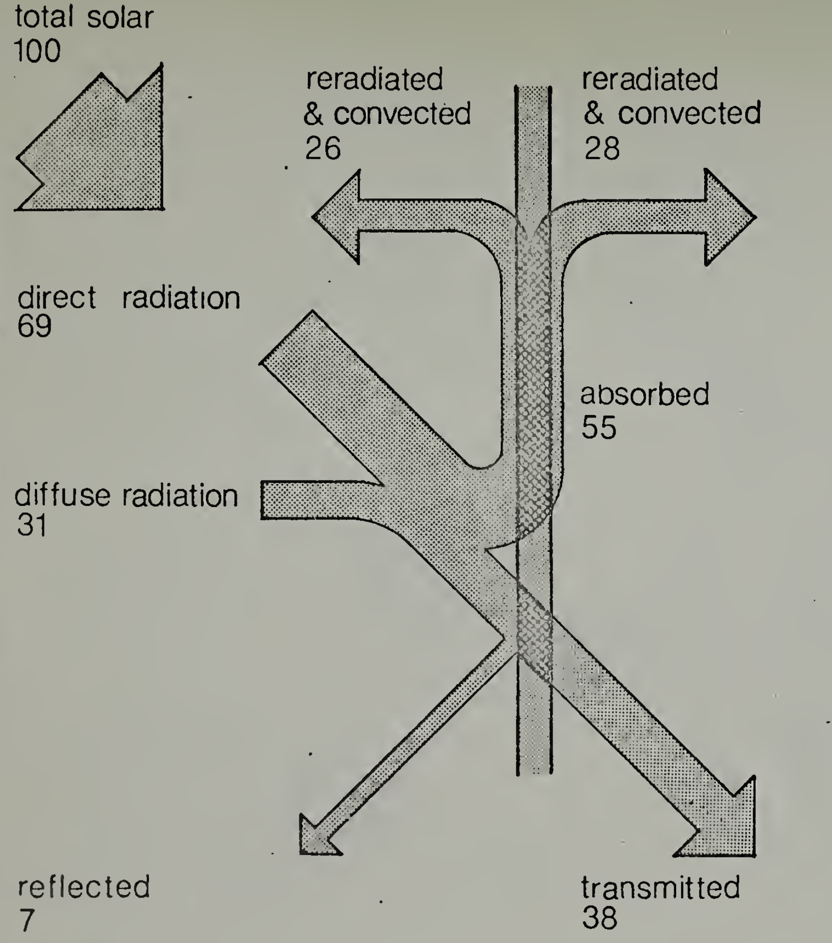
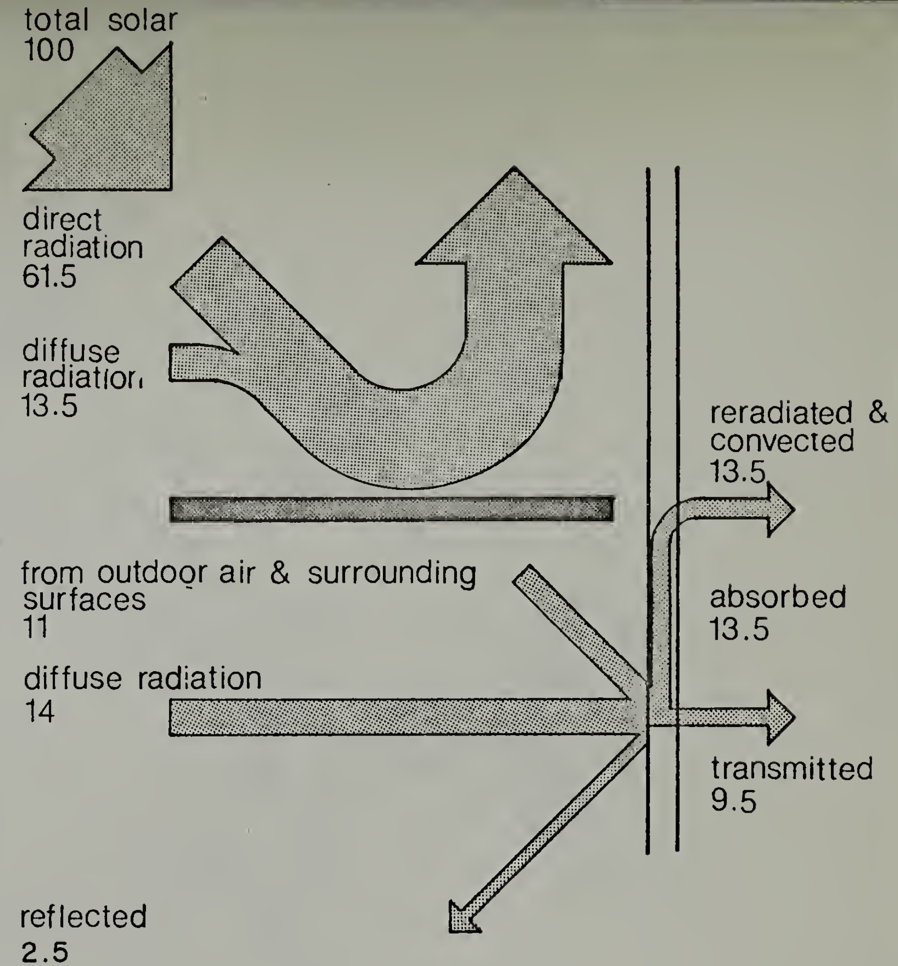


fig. 4.5.1 window heat gain



heat intercepting plate glass- industrial atmosphere

- total admitted: 66%
- 73.5% of quantity admitted by regular plate glass



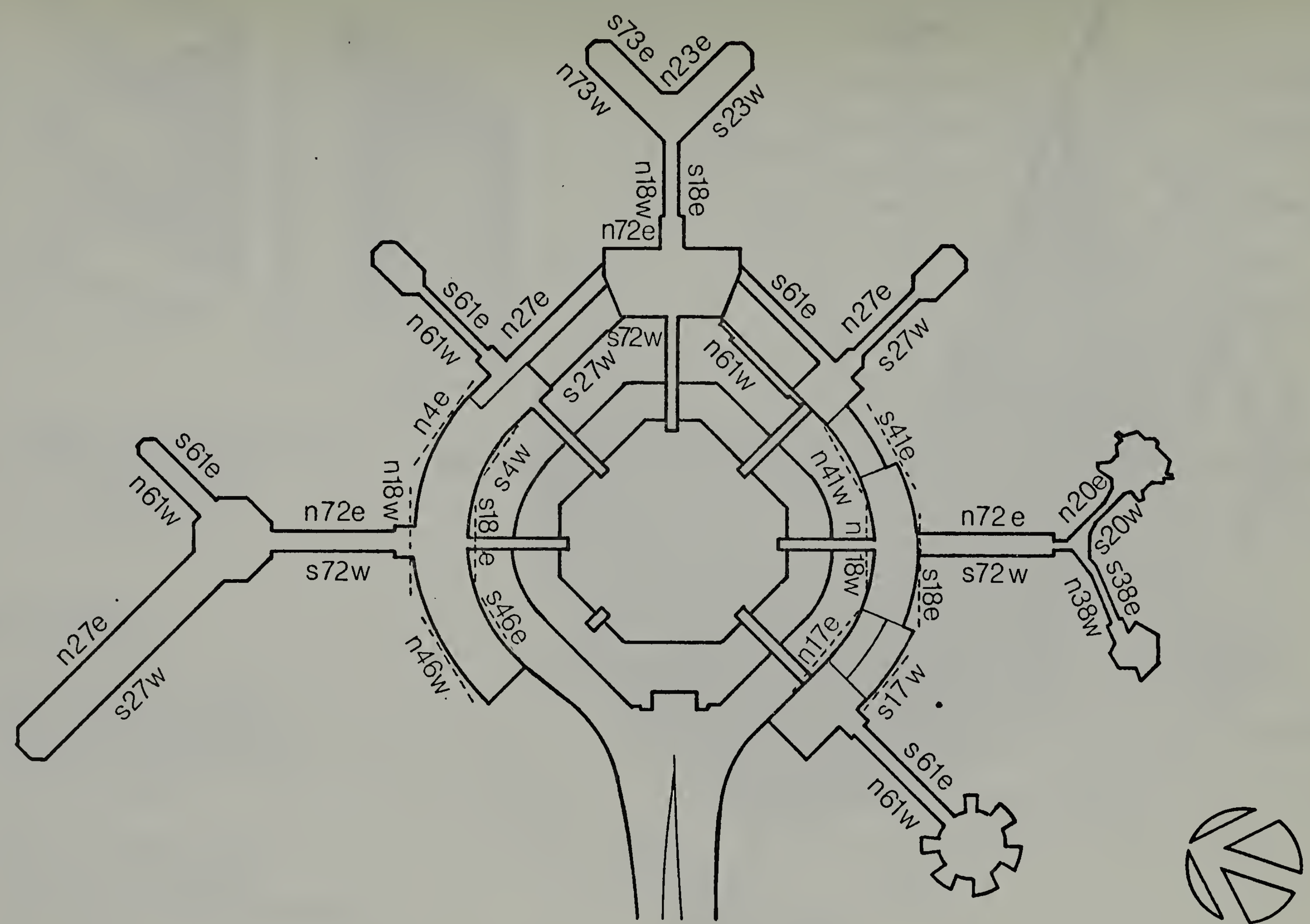
ideal sunshade with regular plate glass- industrial atmosphere

- total admitted: 23%
- 26.5% of quantity admitted by regular plate glass

adapted from solar control & shading devices, a. & v. olgyay, 1957

san francisco international airport — solar feasibility study

fig. 4.6.1 heat flow diagrams- with present glazing & with ideal shading

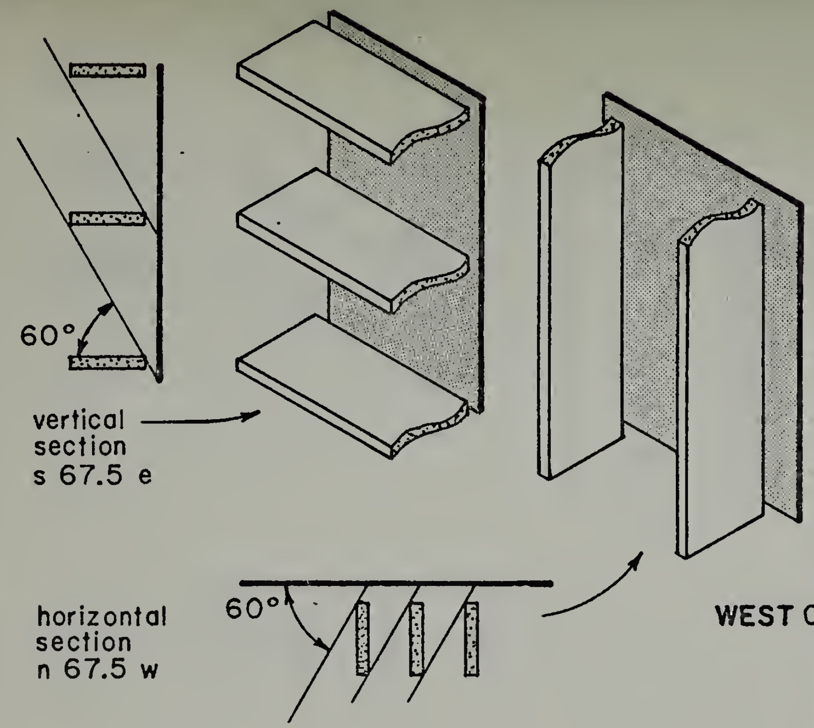


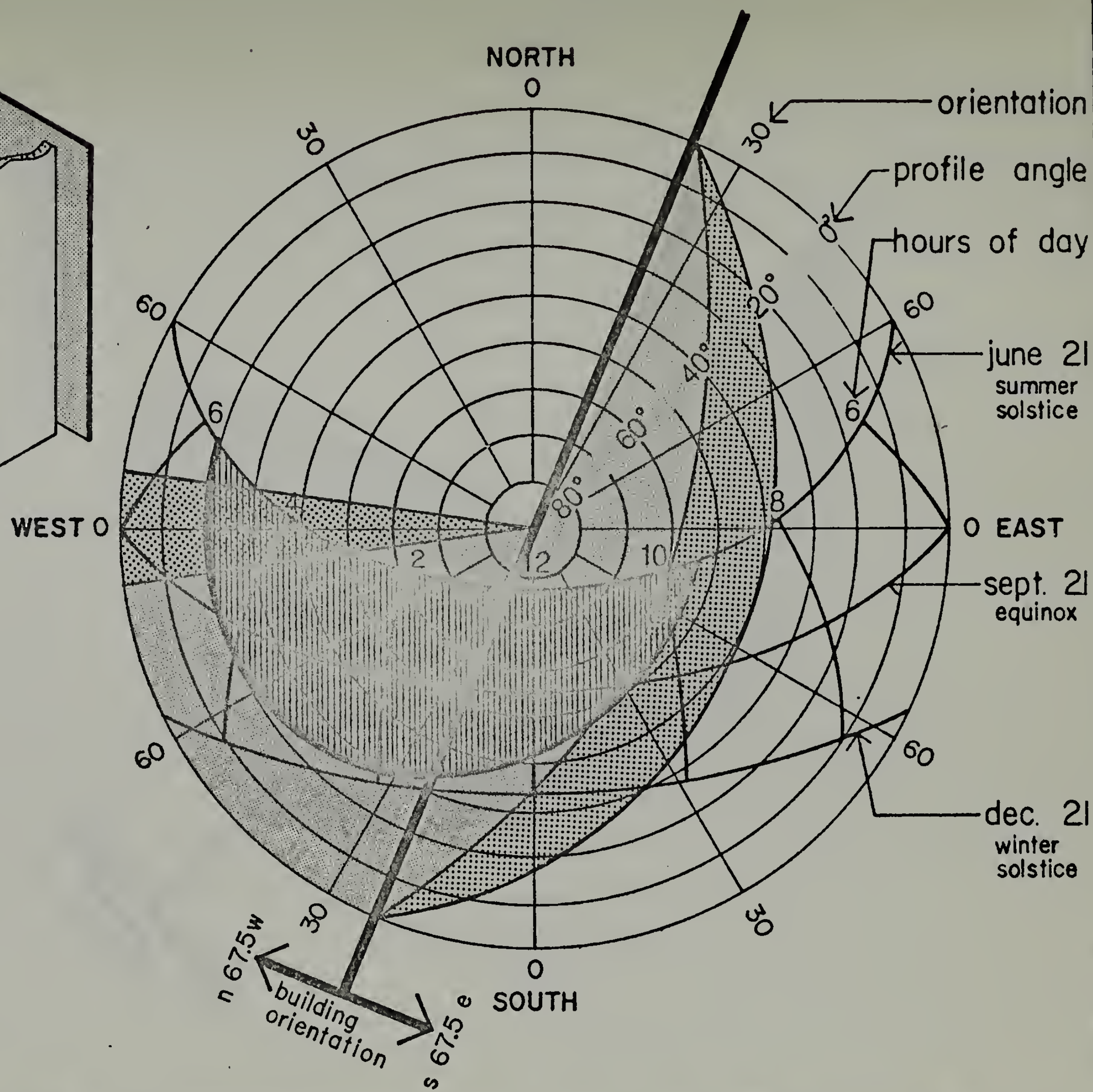
san francisco international airport

solar feasibility study

fig. 4.6.2

facade orientations at SFO





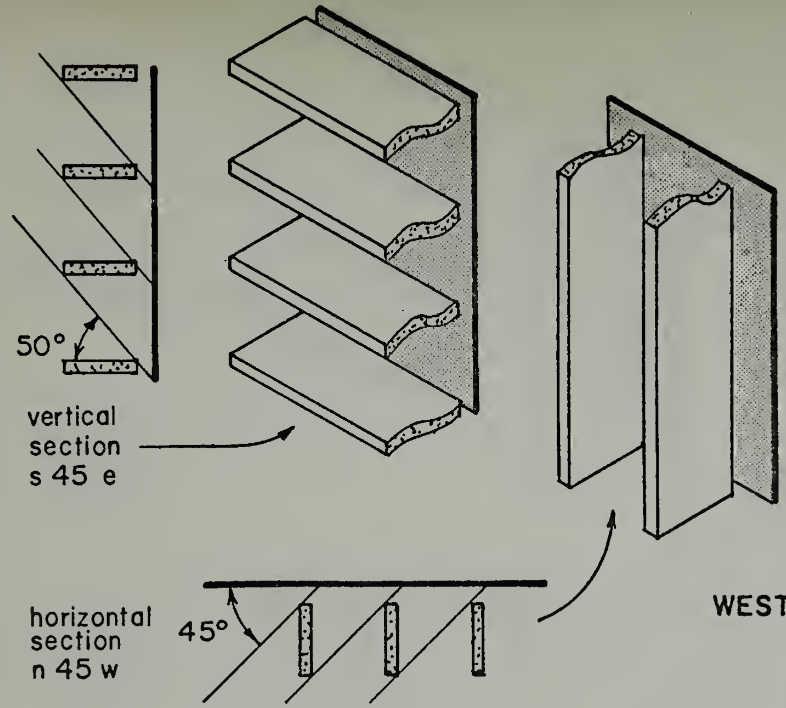
SUGGESTED SHADING

S67.5E: Critical shade angle
60^{O} off the horizontal
Selection of horizontal
shading device.

N67.5W: Critical shade angle
60^{O} off the vertical
Selection of vertical louvers.

san francisco international airport — solar feasibility study

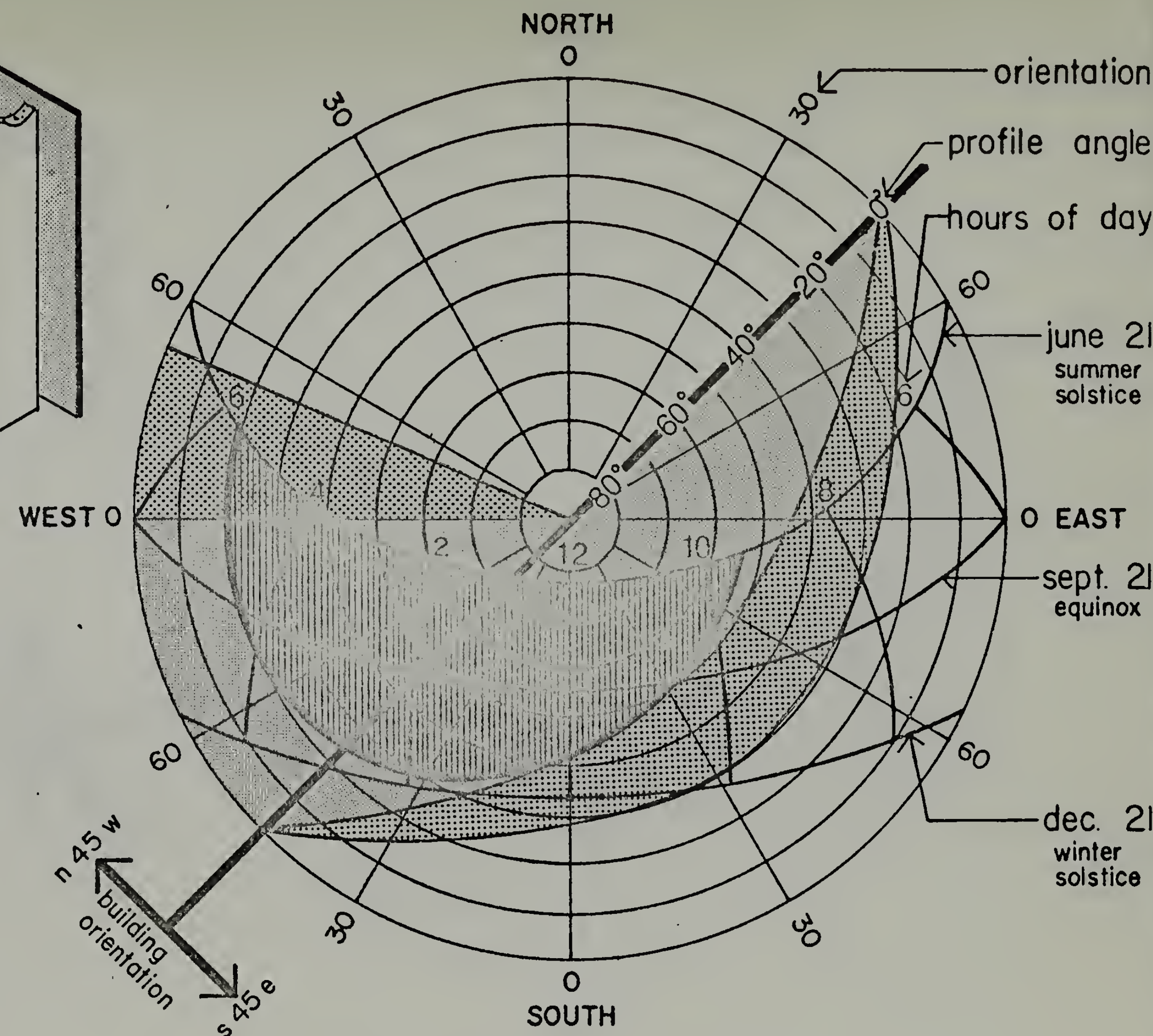
fig. 4.6.3 shading mask- for building elevations n 67.5 w & s 67.5 e



SUGGESTED SHADING

S45E: Critical shading angle 50° off the horizontal Selection of horizontal shading device.

N45W: Critical shading angle 45° off the vertical Selection of vertical shading device.

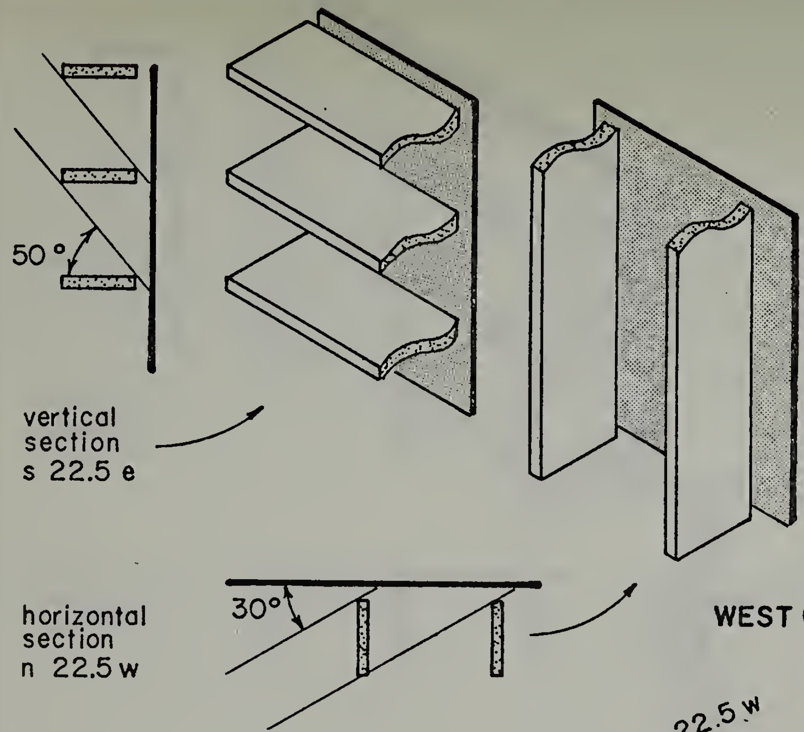


san francisco international airport

solar feasibility study

fig. 4.6.4

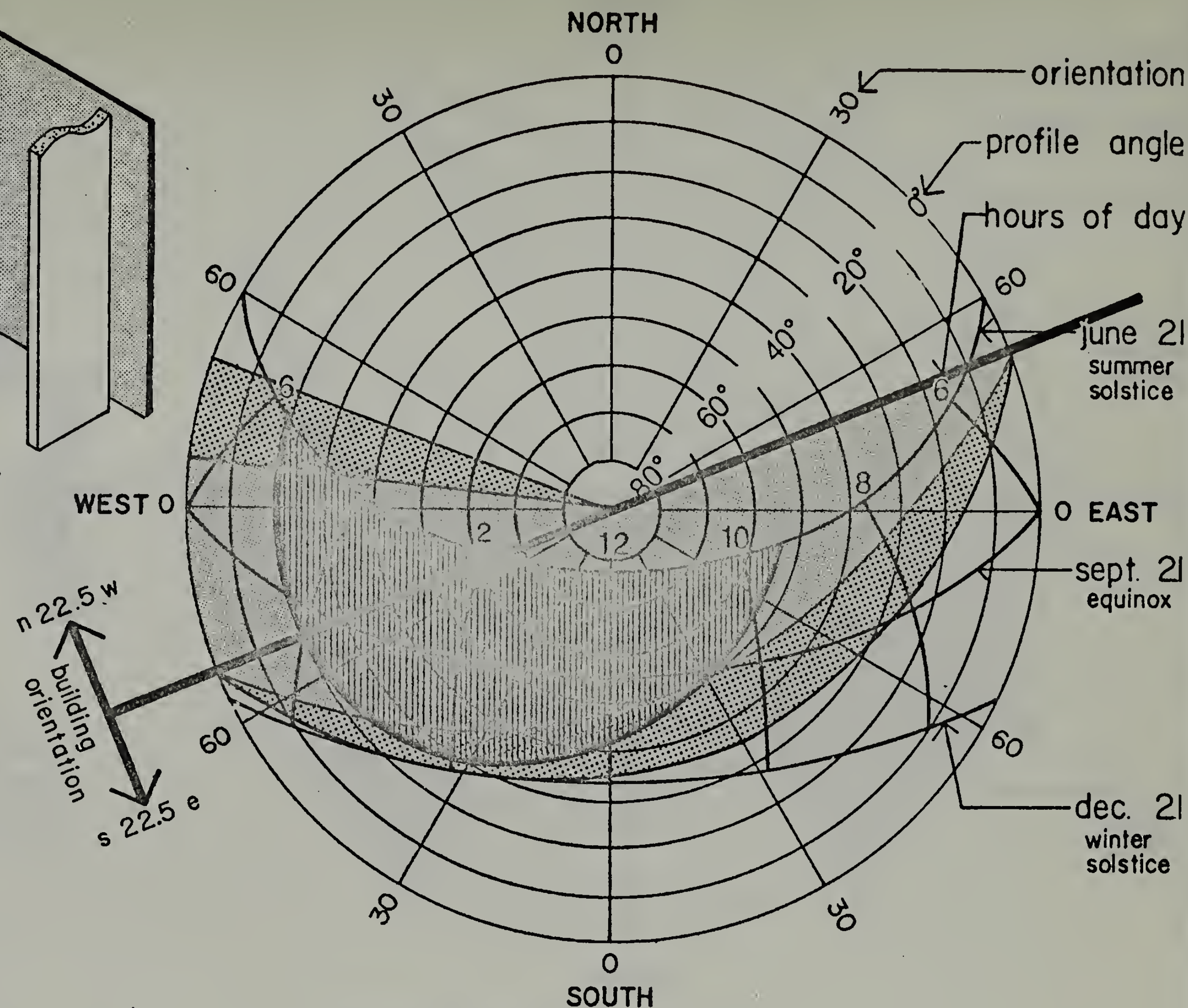
shading mask- for building elevations n 45 w & s 45 e



SUGGESTED SHADING

S22.5E: Critical shade angle 50° off the horizontal. Selection of horizontal louver.

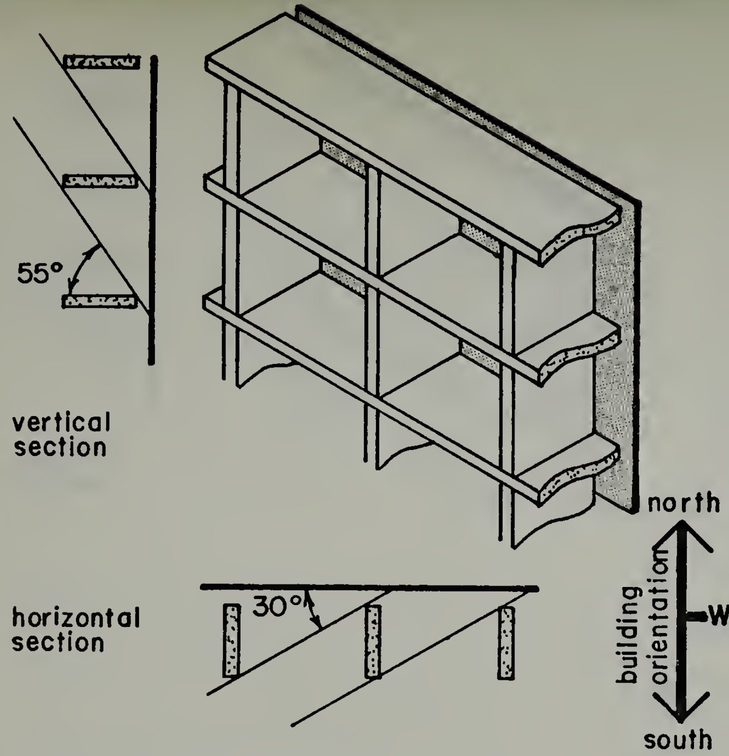
N22.5W: Critical shade angle 30° off the vertical Selection of vertical louver.



san francisco international airport

solar feasibility study

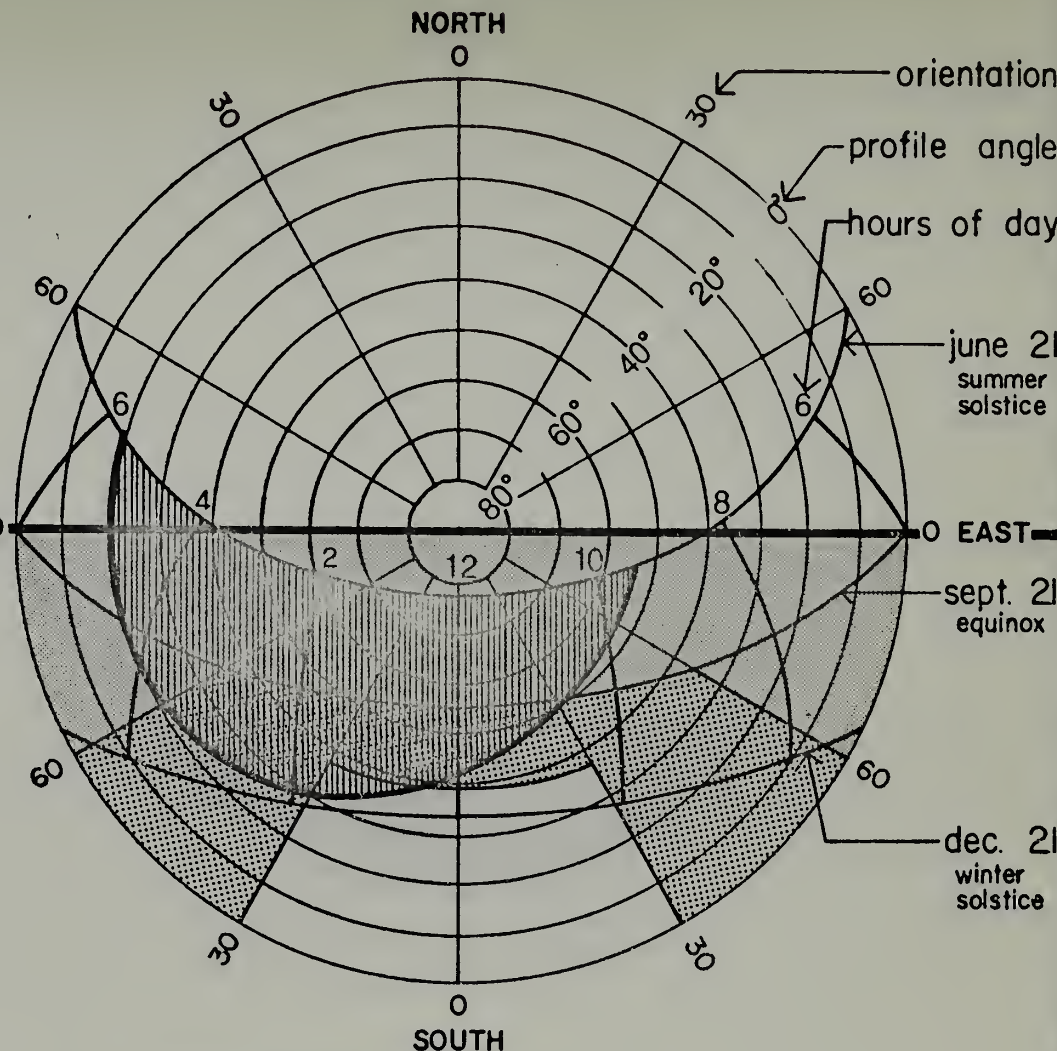
fig. 4.6.5 shading mask- for building elevations s 22.5 e & n 22.5 w



SUGGESTED SHADING

South: Critical sun angle 55° off the horizontal, 30° off the vertical Selection of egg crate designed louvers.

North: No shading required.

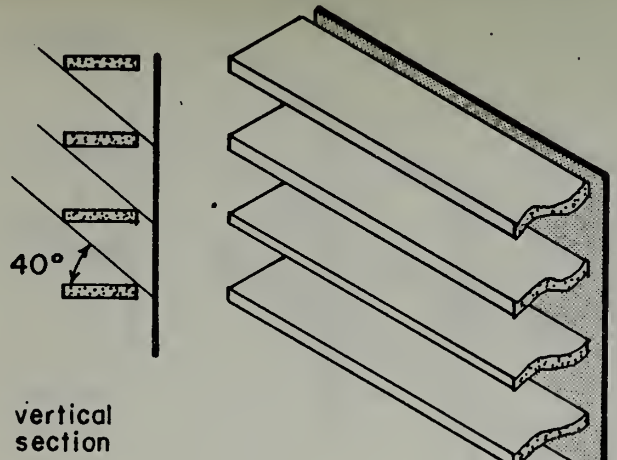


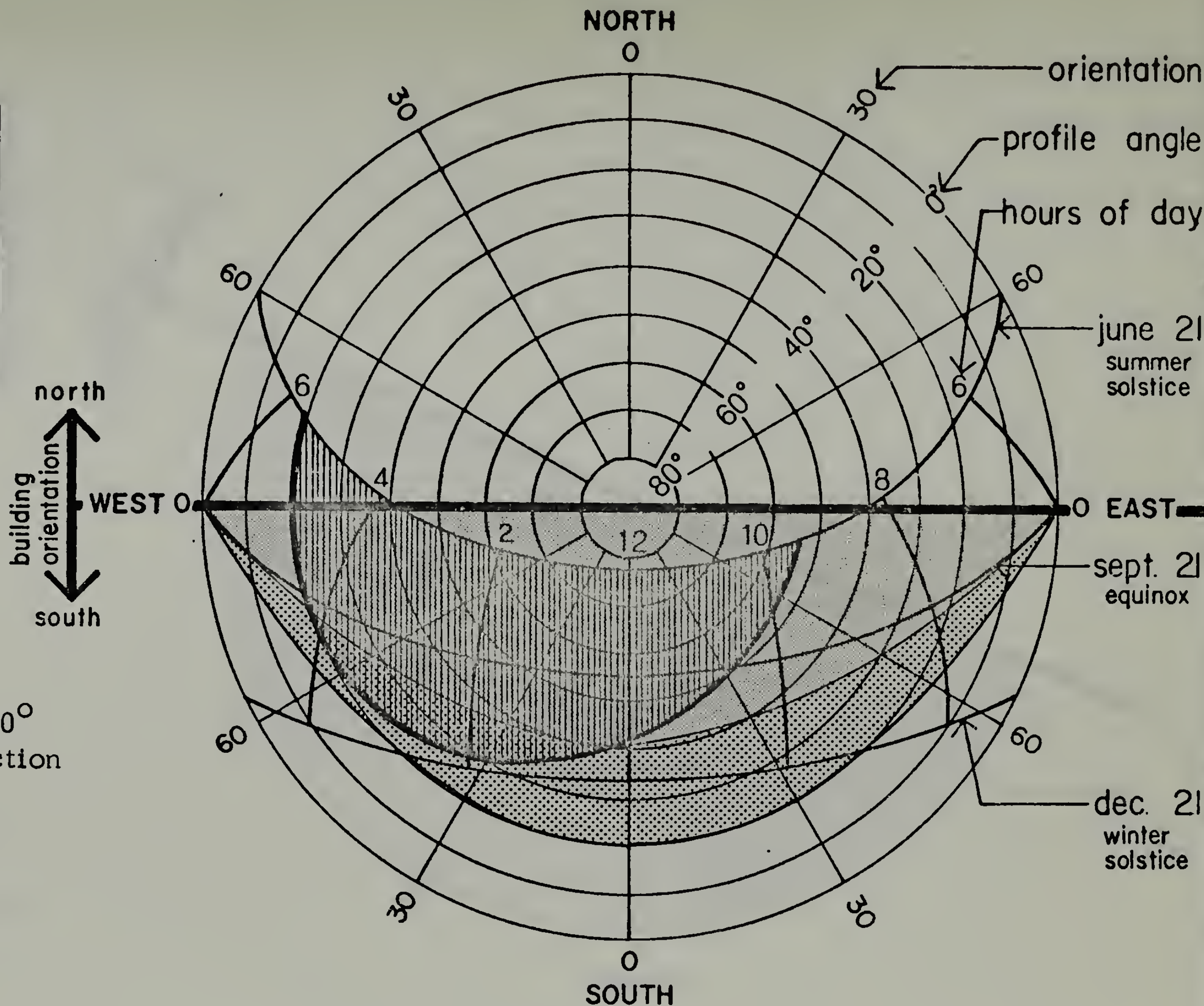
alternative no. 1

san francisco international airport

solar feasibility study

fig. 4.6.6 shading mask- for building elevations south & north





SUGGESTED SHADING

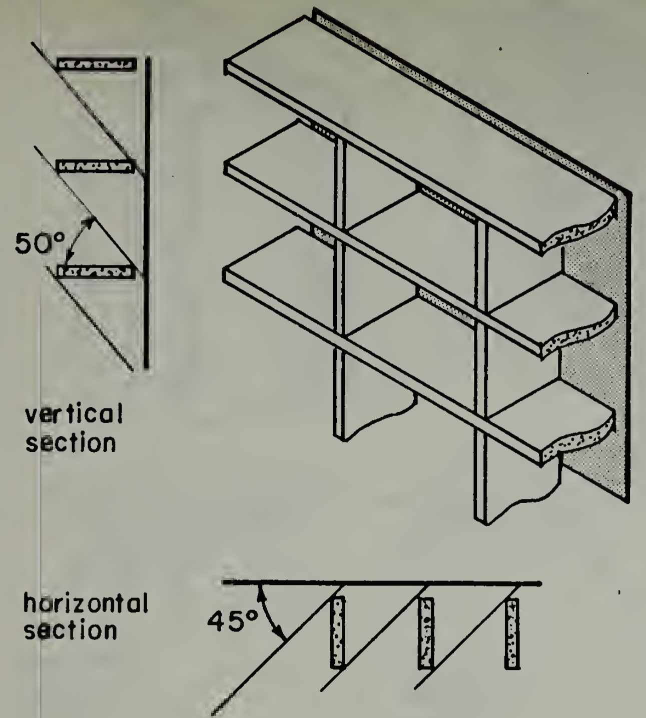
South: Critical sun angle is 40° off the vertical. Selection of horizontal louvers.

North: No shading required.

alternative no. 2

san francisco international airport — solar feasibility study

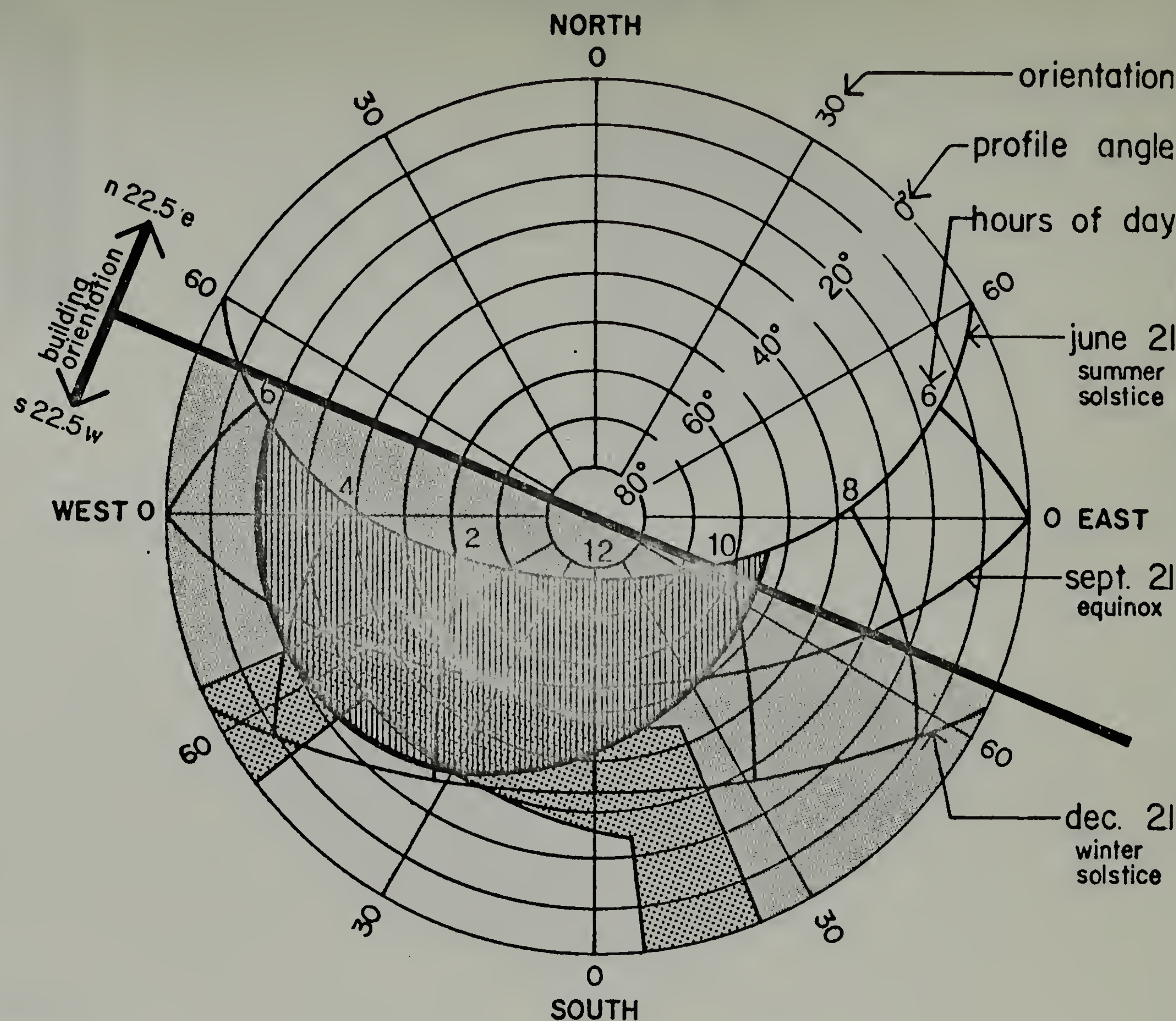
fig. 4.6.7 shading mask- for building elevations south & north



SUGGESTED SHADING

N22.5E : No shading required.

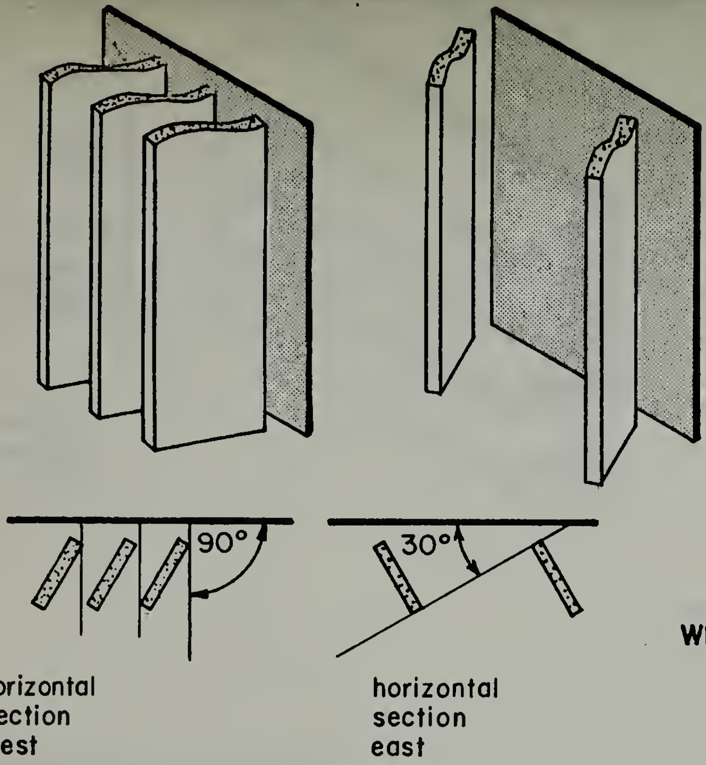
S22.5W: Critical sun angles
50° off the horizontal,
45° off the vertical.
Selection of the egg crate louver design.



san francisco international airport

solar feasibility study

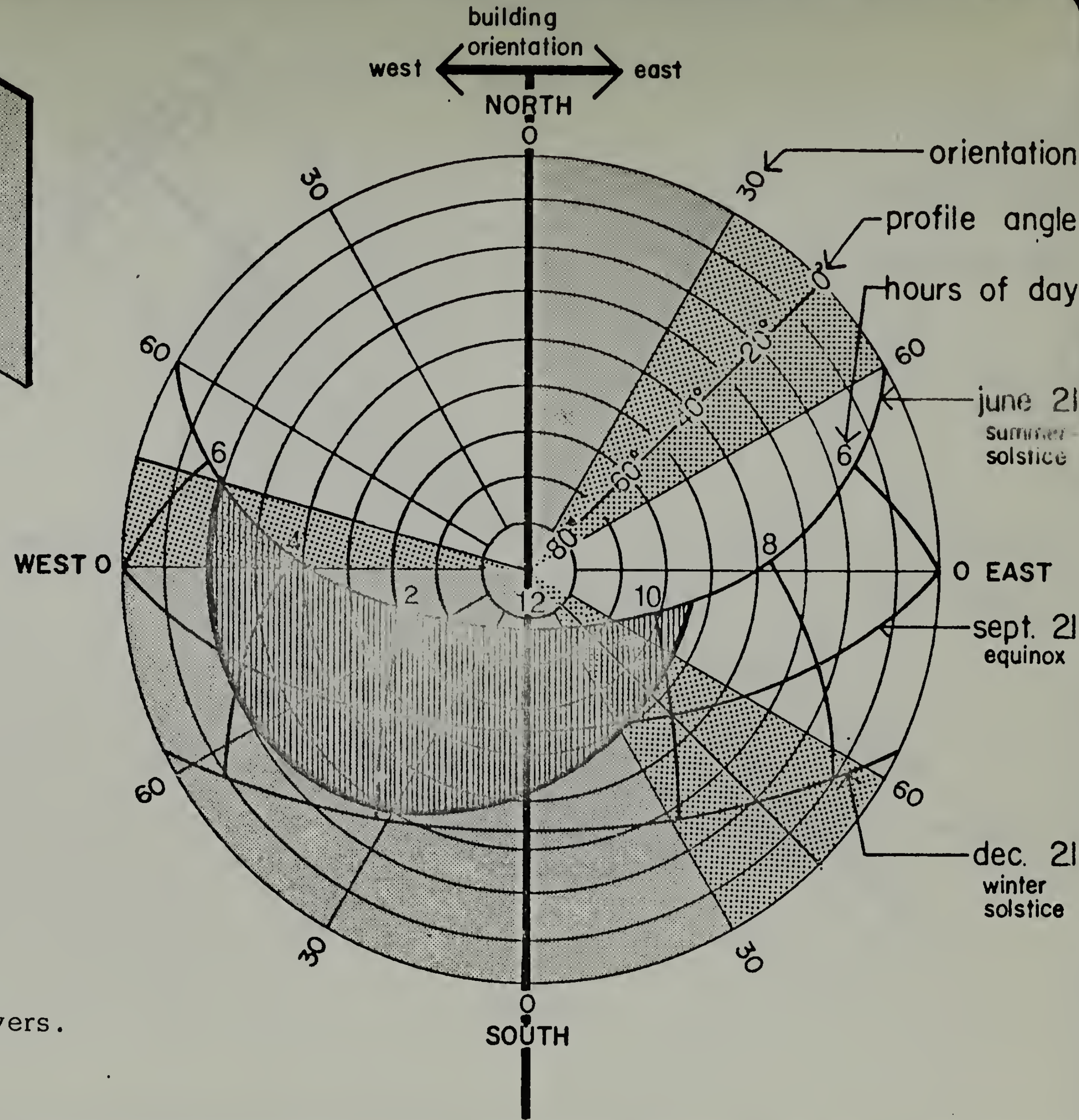
fig. 4.6.8 shading mask- for building elevations s 22.5 w & n 22.5 e



SUGGESTED SHADING

East: Critical sun angle
30° to the vertical
Selection of vertical louvers.

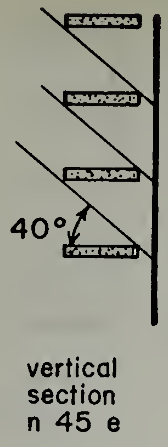
West: Critical sun angle
90° to the vertical
Selection of angled vertical louvers.

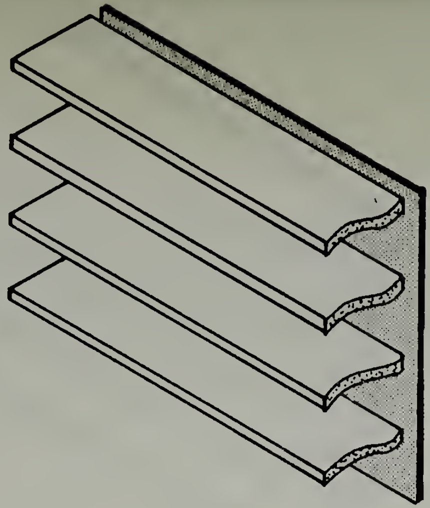


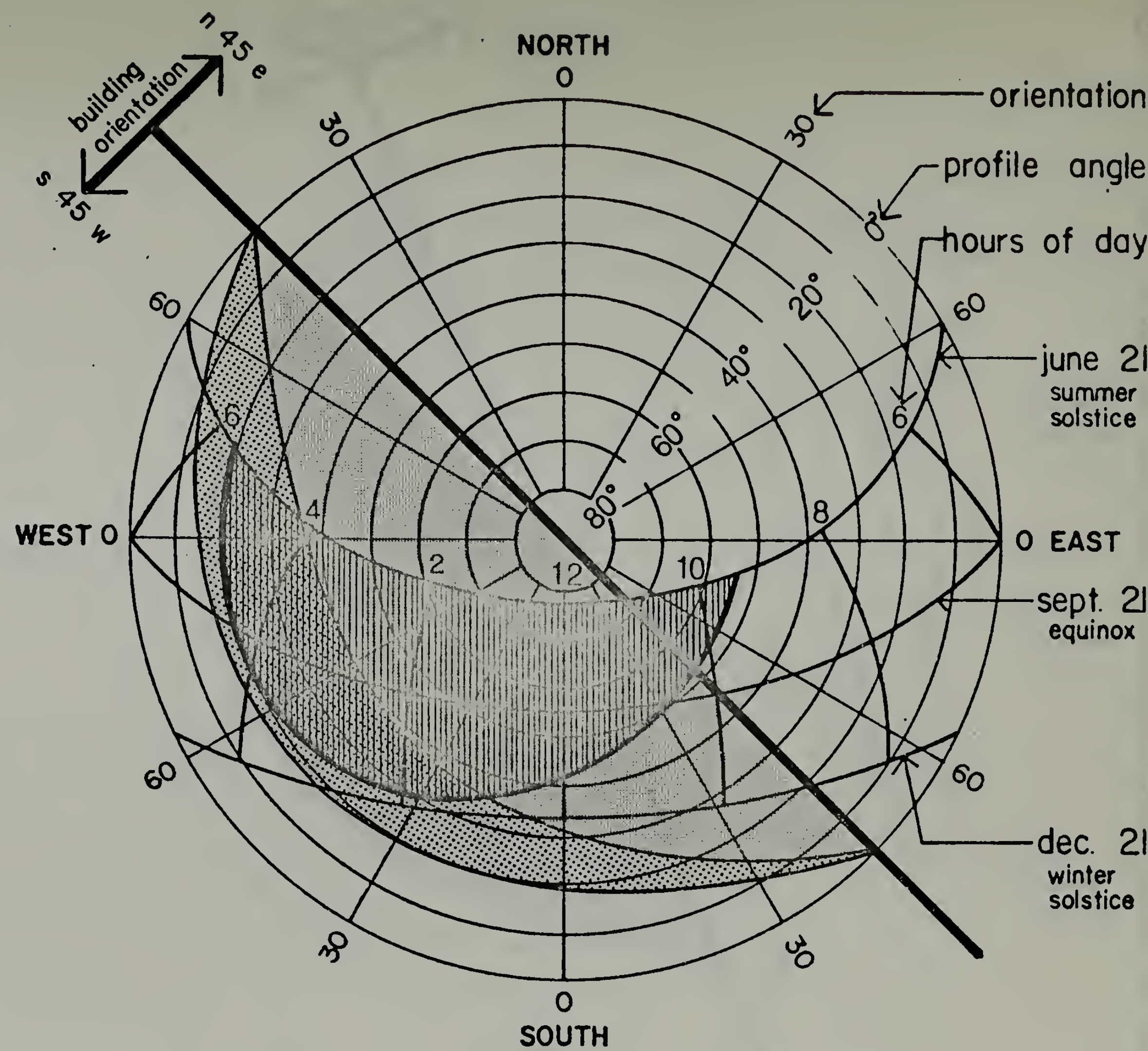
san francisco international airport

solar feasibility study

fig. 4.6.9 shading mask- for building elevations east & west







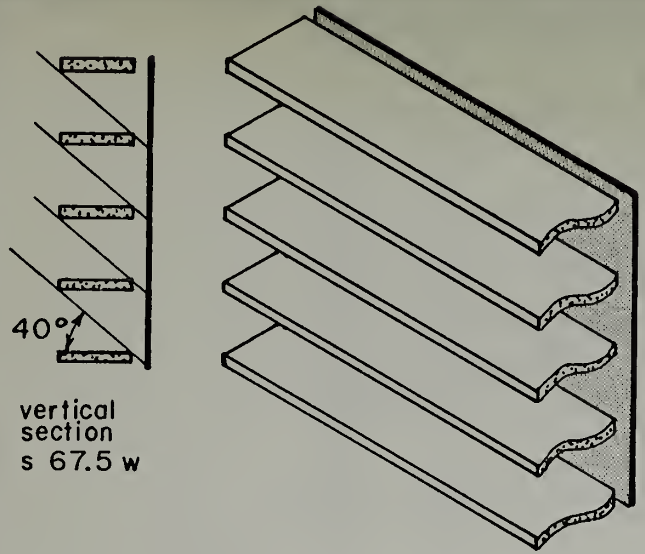
SUGGESTED SHADING

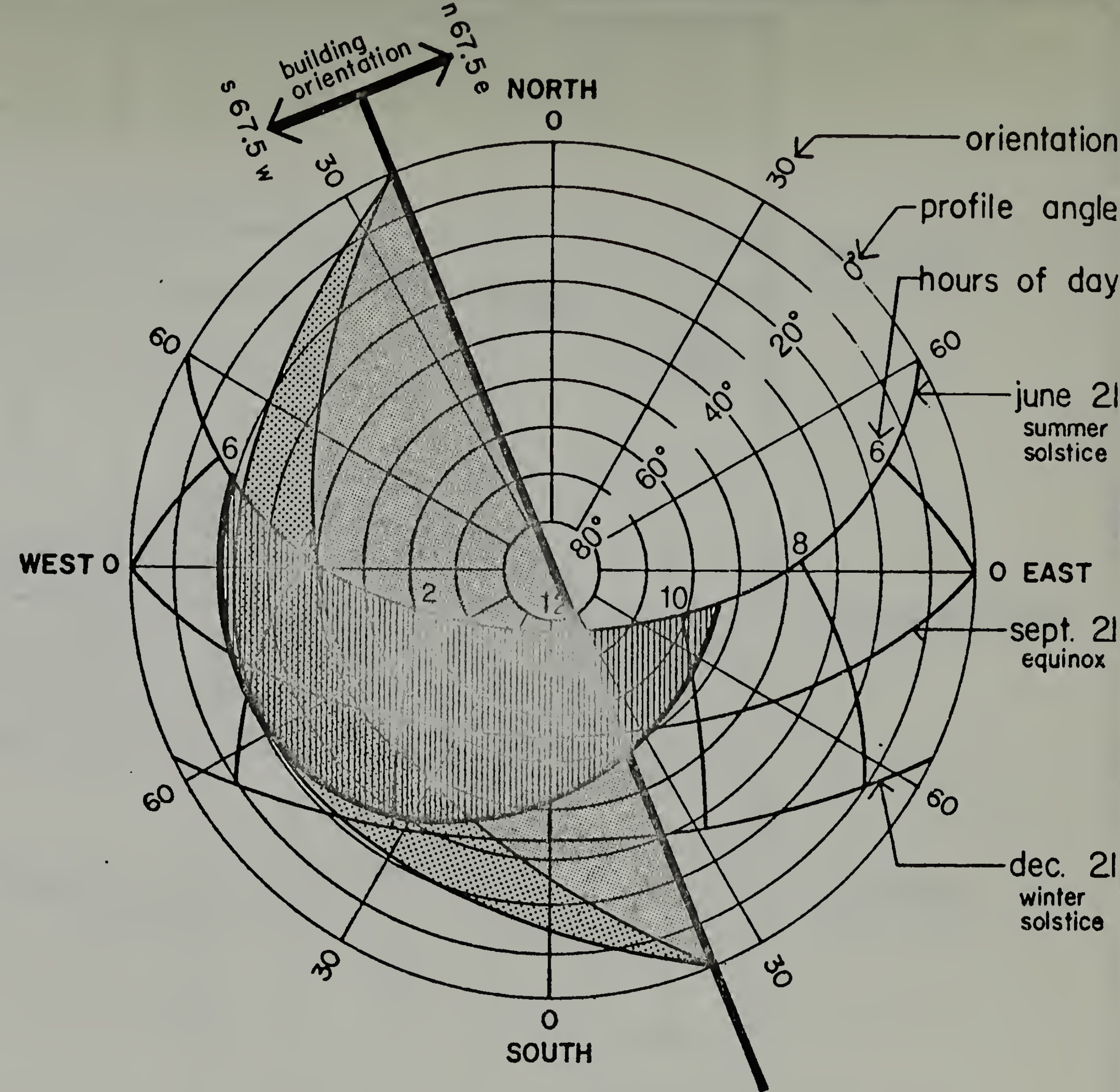
S45W: Critical sun angle is 40° off horizontal. Selection of horizontal louvers.

N45E: Shading not required.

san francisco international airport — solar feasibility study

fig. 4.6.10 shading mask- for building elevations s 45 w & n 45 e





SUGGESTED SHADING

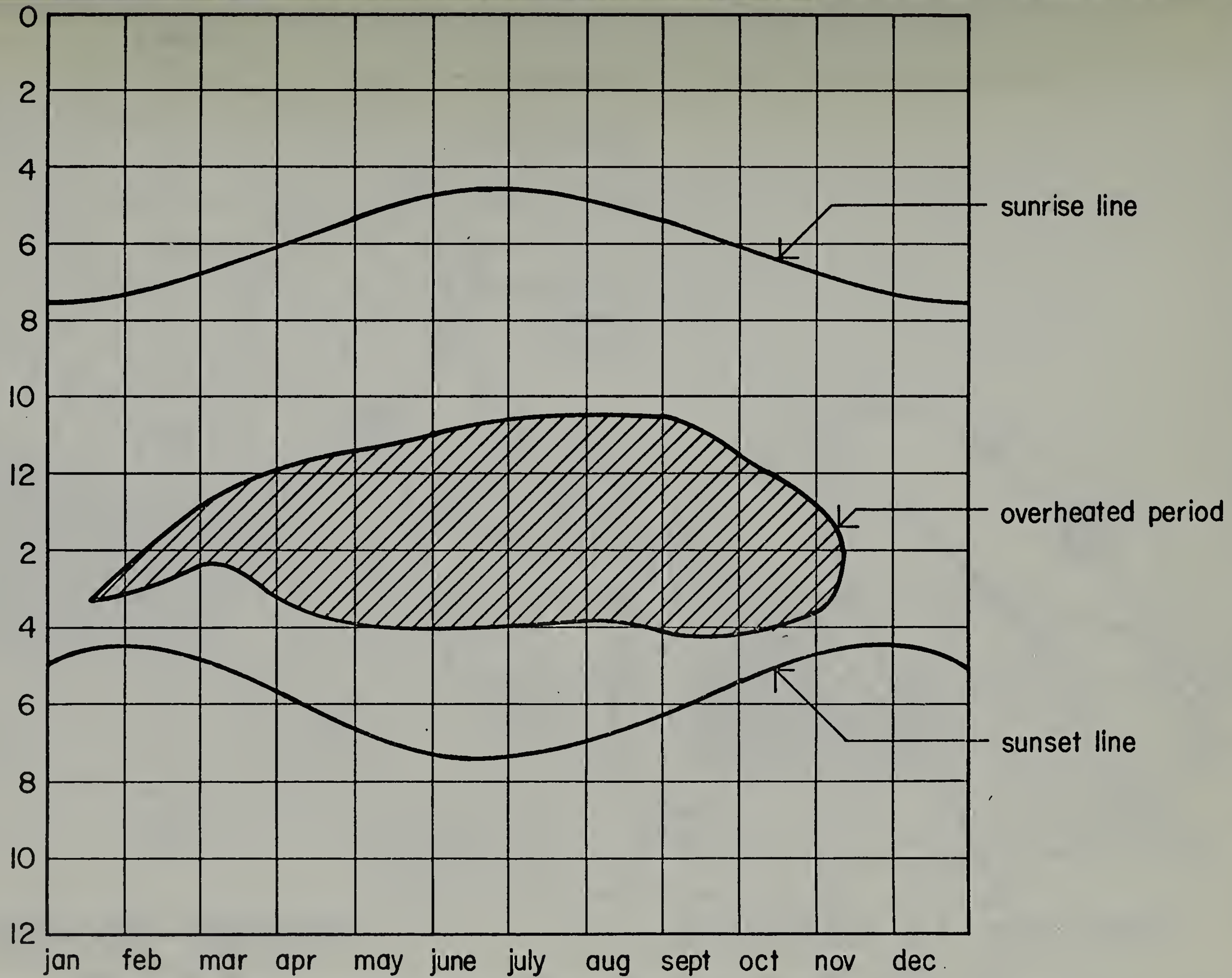
S67.5W: Critical sun angle 40° off horizontal. Selection of horizontal shading device.

N67.5E: Shading not required.

san francisco international airport

solar feasibility study

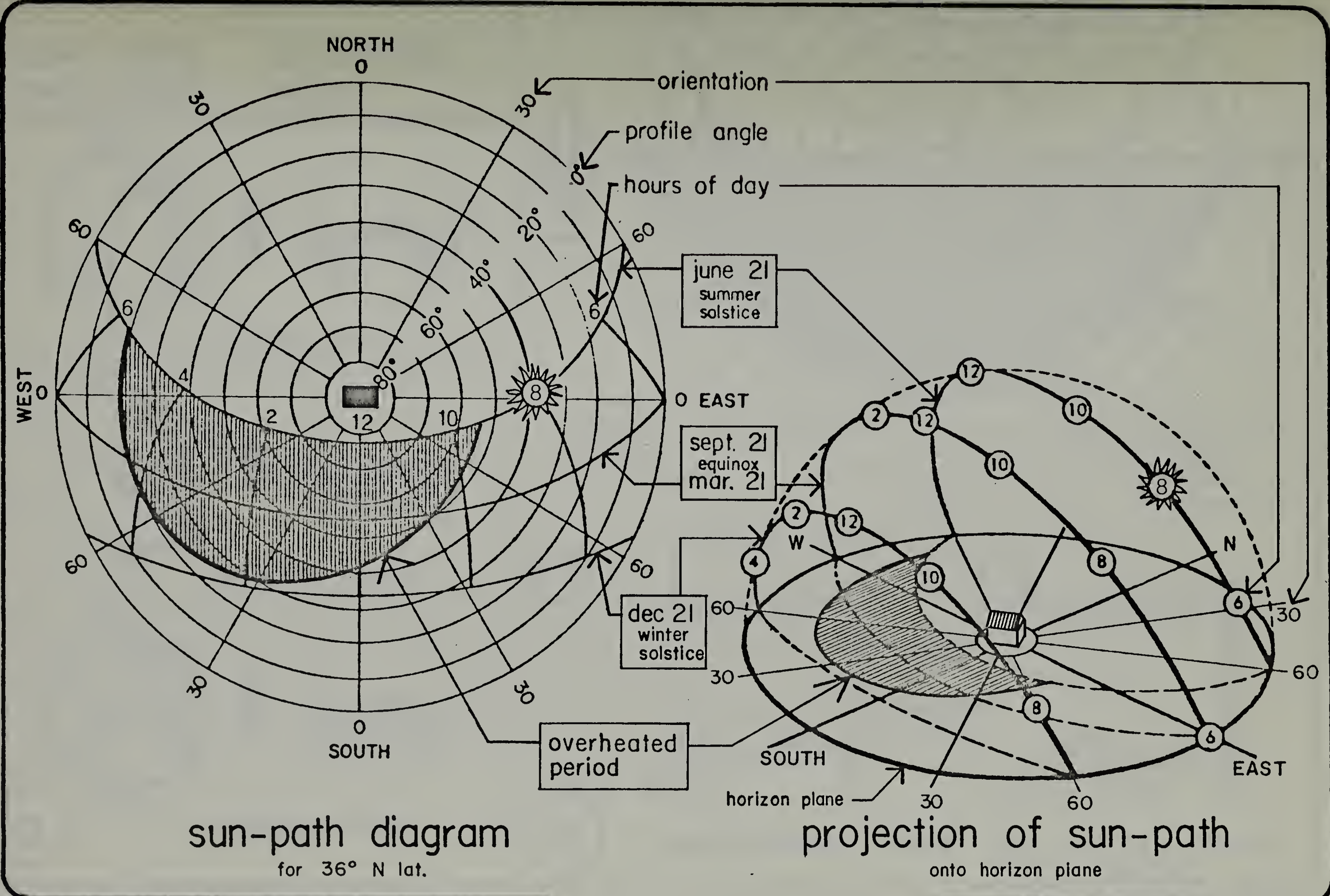
fig. 4.6.11 shading mask- for building elevations s67.5w & n67.5e



san francisco international airport

solar feasibility study

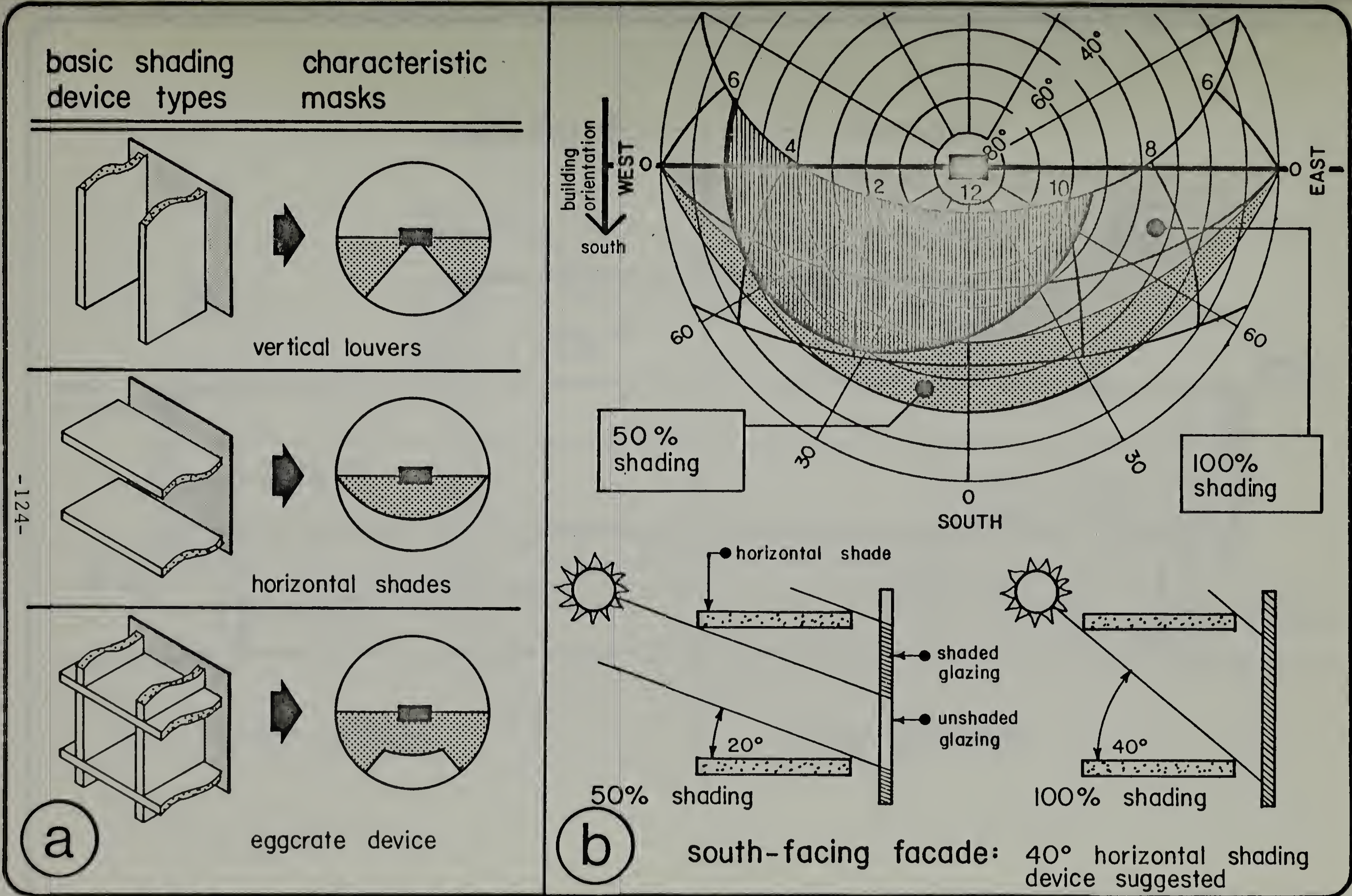
fig. 4.6.12 overheated period chart for SFO



san francisco international airport

solar feasibility study

fig. 4.6.13 overheated period transferred to sun-path diagram



san francisco international airport

solar feasibility study

fig. 4.6.14 characteristic shading masks and their application

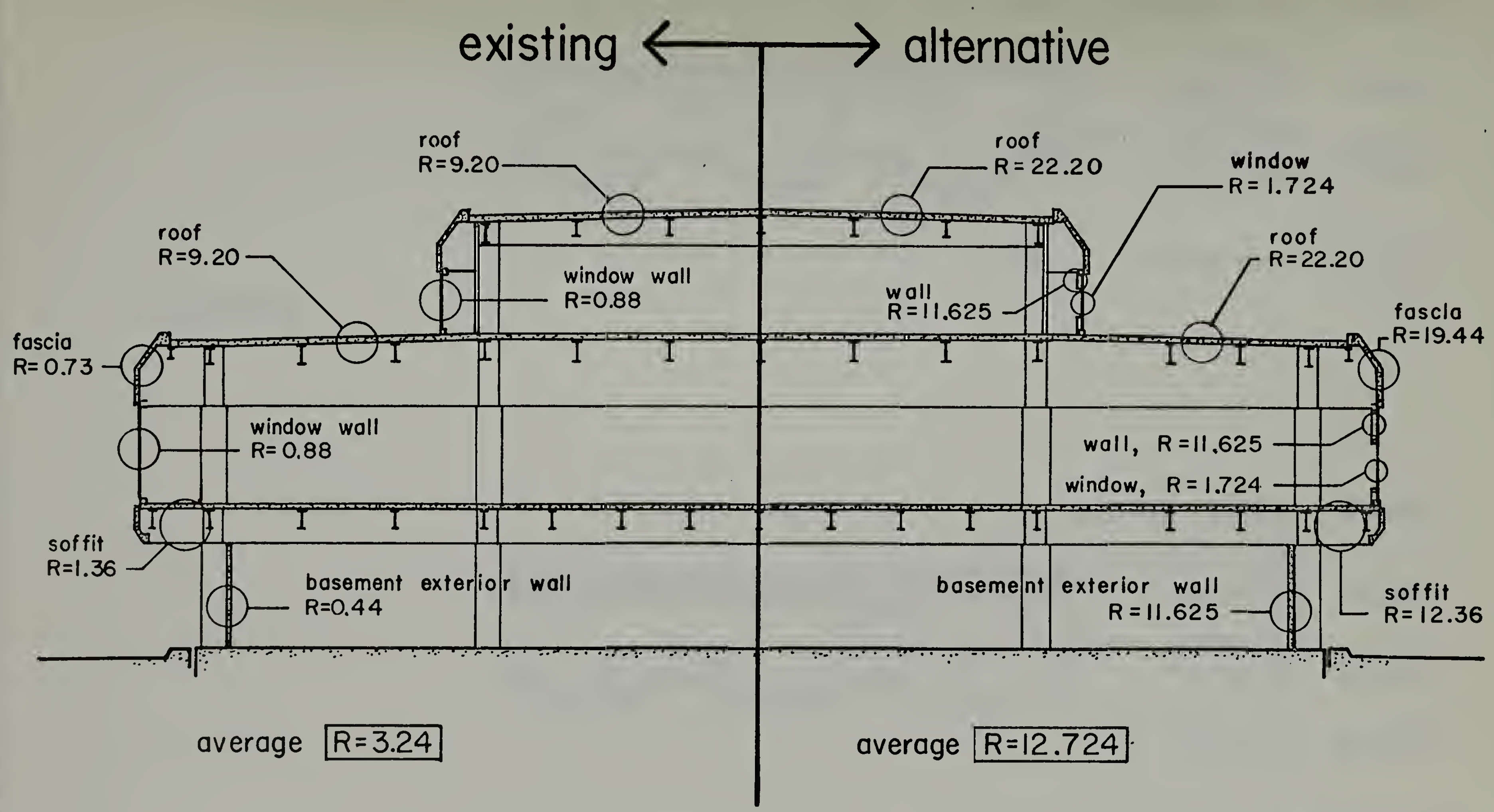
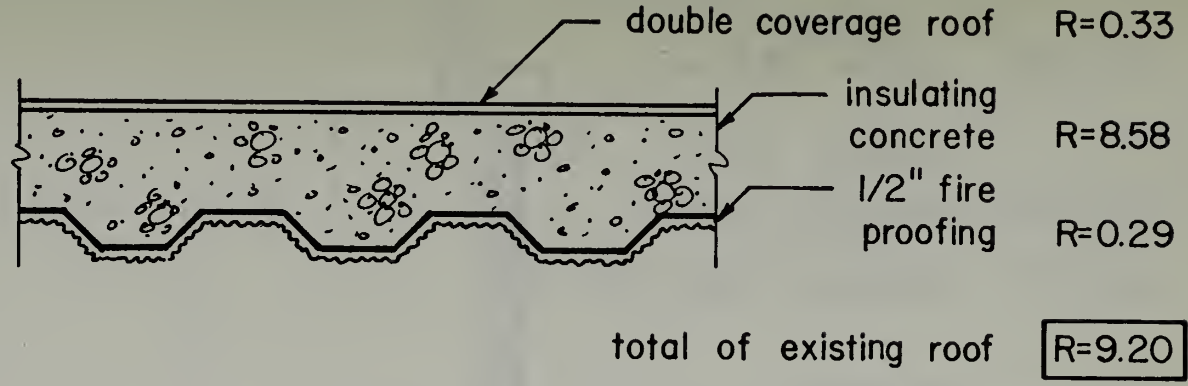


fig. 4.7.1 transverse section - existing & alternative conditions

existing



alternative

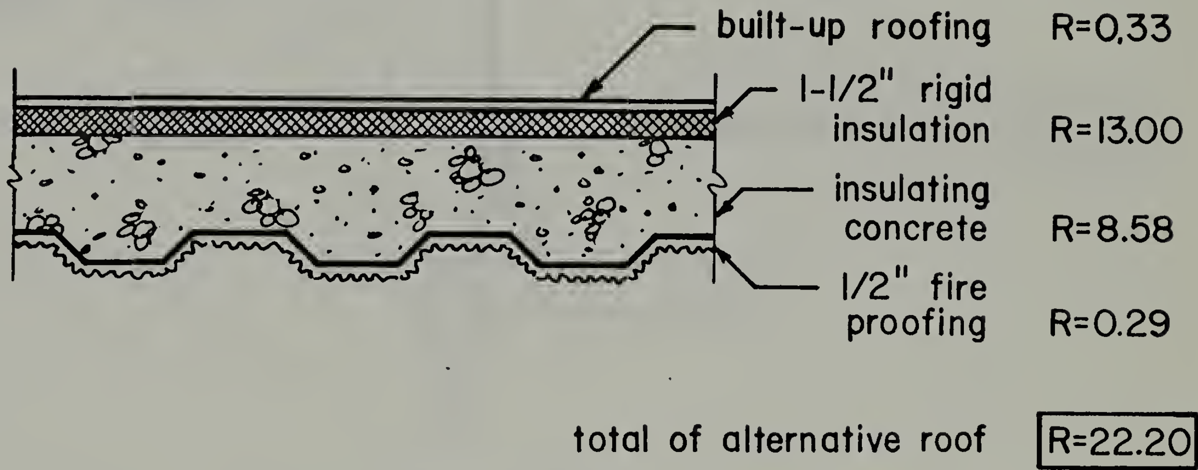
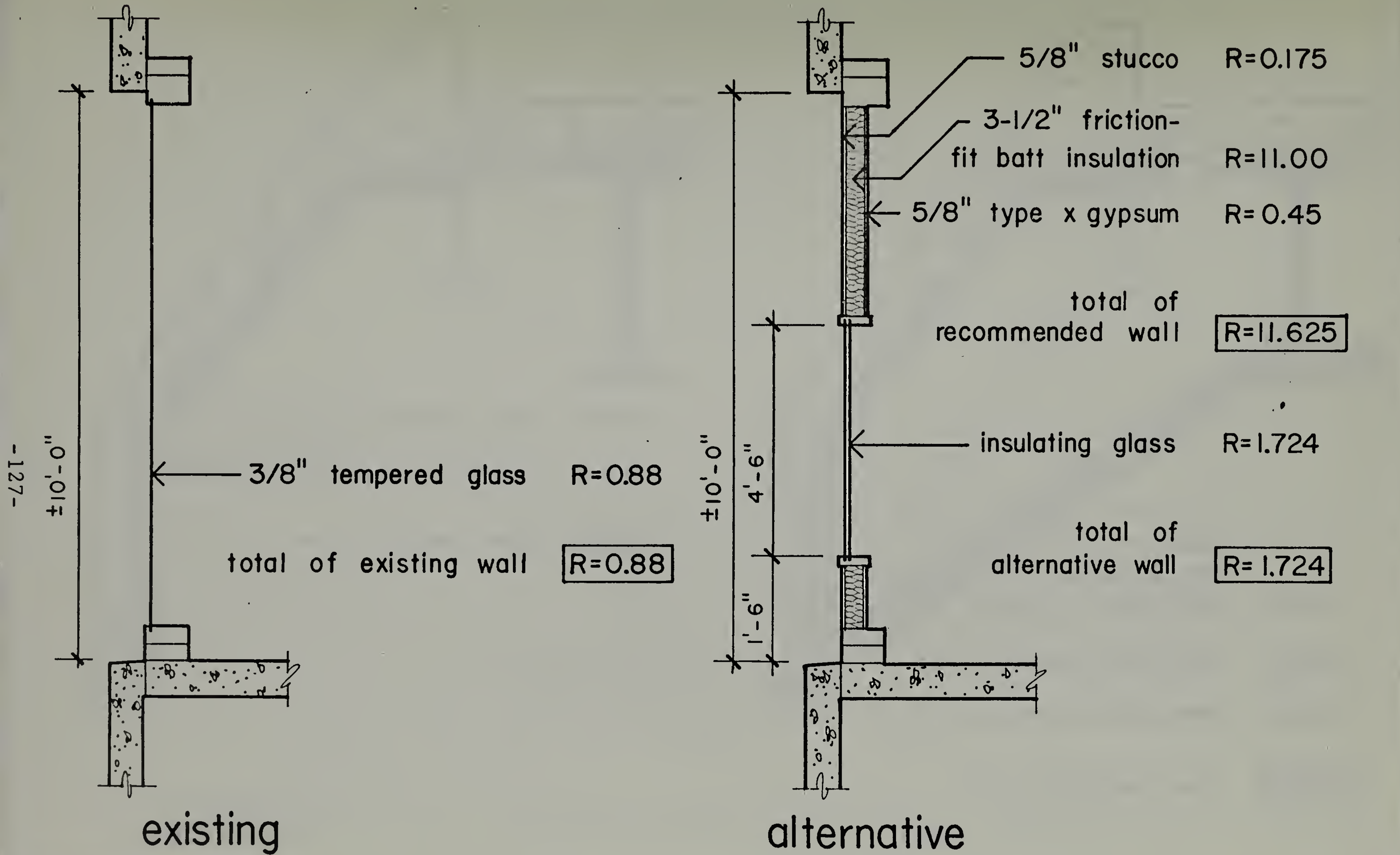


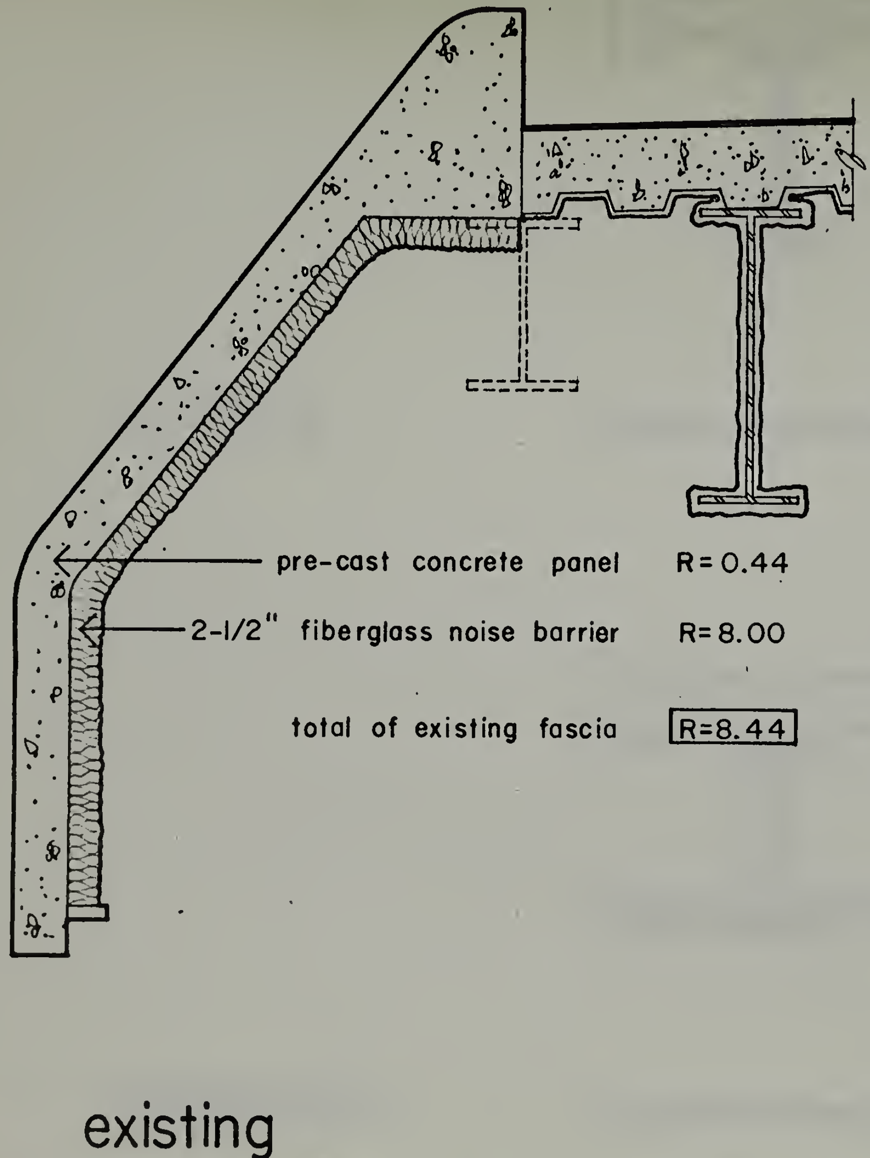
fig. 4.7.2 roof

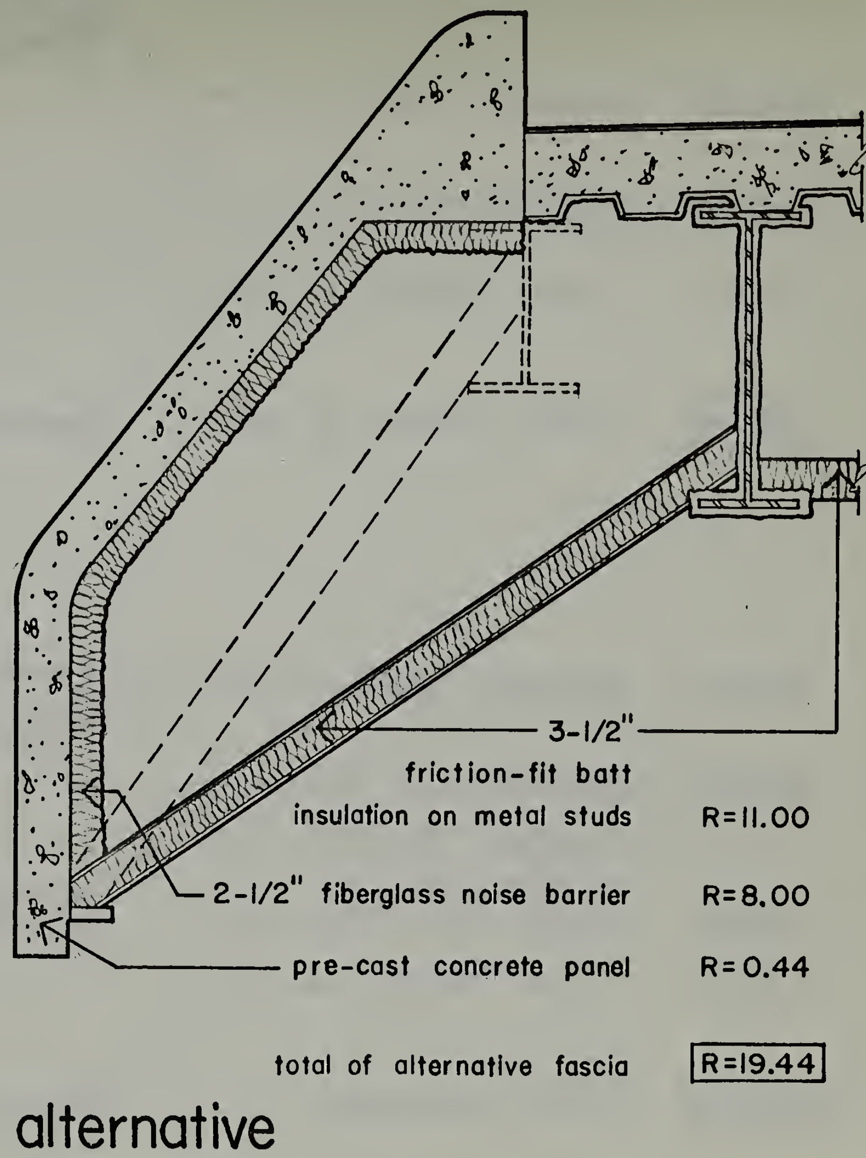


san francisco international airport

solar feasibility study

fig. 4.7.3 window wall





san francisco international airport

solar feasibility study

fig. 4.7.4 fascia

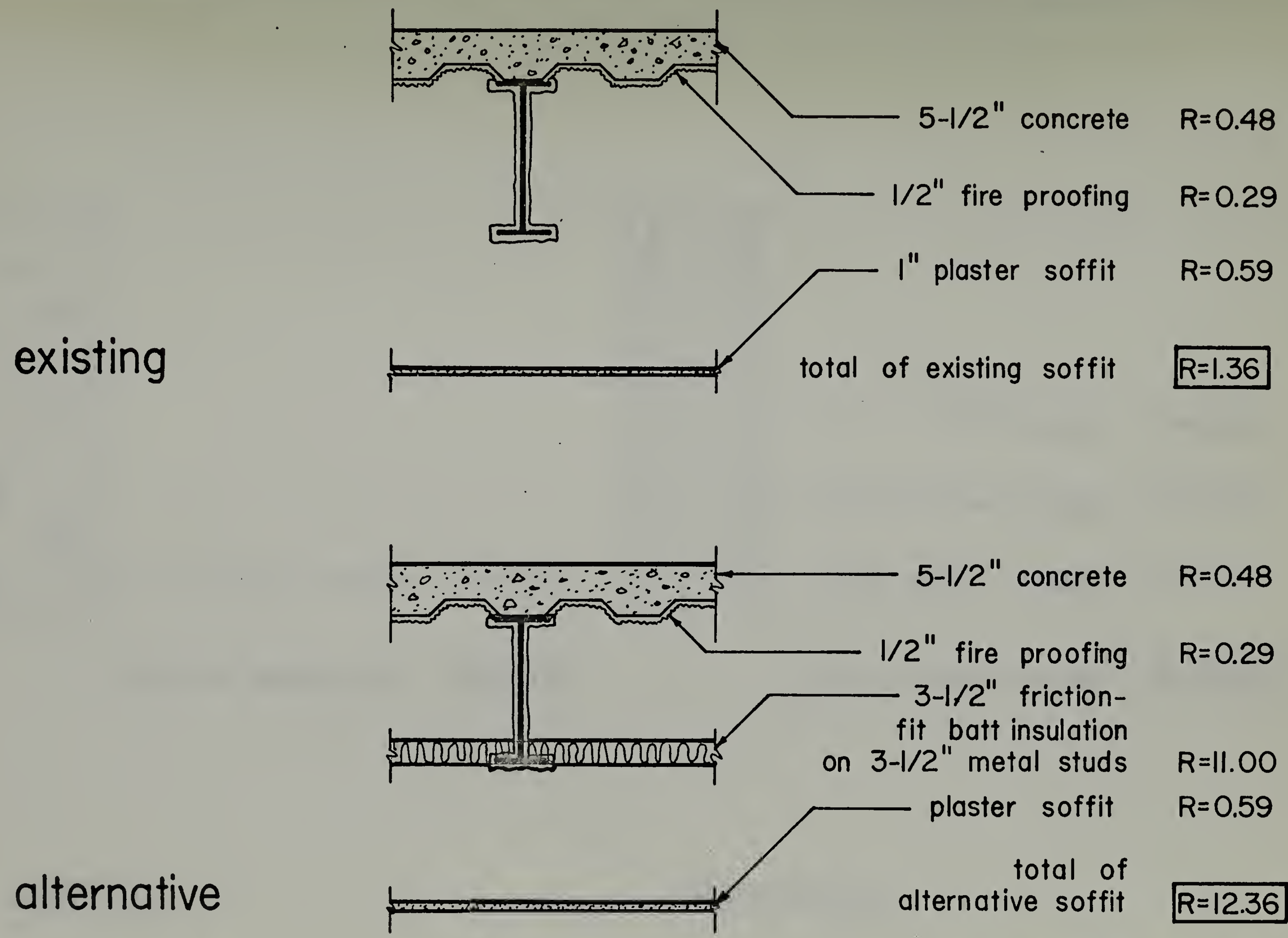
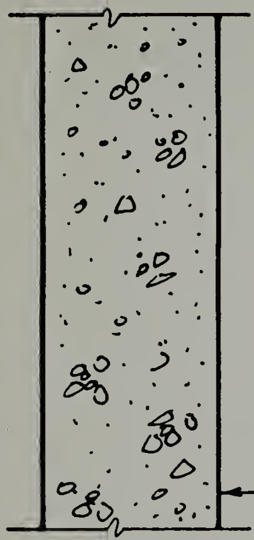


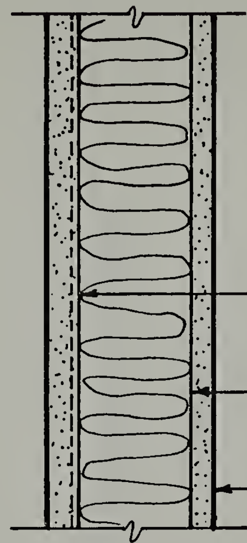
fig. 4.7.5 soffits



5-1/2" concrete R=0.44

total of existing wall $\boxed{R=0.44}$

existing



5/8" stucco R=0,175

3-1/2" friction fit batt R=11.00

5/8" type x gypsum R=0.45

total of alternative wall $\boxed{R=11.625}$

alternative

san francisco international airport solar feasibility study

fig. 4.7.6 basement exterior wall

SECTION 5

ENERGY CONSERVATION

5. Energy Conservation

In a facility as large and complex as the airport, there are virtually unlimited opportunities to conserve energy. The following recommendations represent those opportunities which are particularly advantageous. Efforts to conserve energy are typically much more cost-effective than efforts to produce it from alternate sources and, therefore, should receive high priority.

5.1 Lighting

a. Fluorescent Lamp Change. All lamps should be changed in all fluorescent fixtures in the South and Central Terminals and all piers from the standard 40-watt lamps to the new "watt-miser" 35-watt lamps by General Electric, Sylvania, etc. This could be done at the regular relamping period by the maintenance department at no extra installation costs. Extra cost for this lamp over the standard lamp is 25 cents per lamp or 16 per cent initially. There are approximately 19,000 lamps in the public areas. With a five-watt savings per lamp there is a potential savings of 95,000 watts or 832,200KWH per year (95KW x 8,760 hours per year). At the present rate of three cents per KWH this provides a savings of $24,966 per year. The light levels would be decreased by approximately 10 per cent and would not be noticeably lower that the current light levels.

b. Ballast Change. Whenever ballasts are replaced in any fluorescent fixture, they should be replaced with new super premium-type, very low heat ballasts. These ballasts are 10 per cent more efficient than standard class "P" ballasts. Since they operate at a lower temperature, their life span is about 1.7 times that of the standard ballasts. This means that the normal life span of the ballasts would increase from six years (operated 24 hours a day) to over 10 years. Replacement costs would be reduced accordingly. Extra cost for these ballasts is about 75 cents or 10 per cent over a standard ballast. These ballasts are generally available from most manufacturers.

c. Incandescent Lamp Change. In areas where incandescent fixtures are used, the lamps should be replaced with the next lowest wattage type. This would reduce energy consumption considerably and only reduce light levels about 25 per cent, from 70 to 53 footcandles (fc), which is still very tolerable.

d. <u>South Terminal Light Reduction</u>. The main lobby areas of the South Terminal are provided with general lighting from the 22-foot-high ceiling by two-lamp fluorescent one-foot by eight-feet fixtures. They are mounted in rows of two about 22 feet apart. The footcandle level in these areas is around 40 fc during the day, but little is contributed from these fixtures. When they were turned off, the footcandle level only dropped to about 35 fc. It is our recommendation that half of these fixtures by turned off by means of a time clock during the daylight hours. This would still provide adequate lighting for the mezzanine walkways above and on cloudy days. This could be easily accomplished by mounting a time switch and contactor next to the appropriate panel and connecting it to the proper circuits. The cost for this installation would be about $1,500. With these fixtures turned off 10 hours a day, the energy saved would be 186,150 KWH per year (51KW x 3,650 hours). At three cents per KWH this results in a savings of $5,584 per year. The ticket counters and tenant areas all have adequate supplemental lighting and would not be adversely affected by this reduction.

e. <u>Central Terminal Light Reduction</u>. In the main lobby area there is a 22-foot-high luminous ceiling that adds little to the daylight illumination of this area. About 30 per cent of the lamps were burned out when light readings were taken at the United Airlines ticket islands, and they were getting from 30 to 40 fc during the day. The same method could be used here to reduce energy consumption by switching off half of the lamps in the luminous ceiling during the day with time switches and contactors at a cost of about $2,000. The energy savings would be 31,025KWH per year (8.5KW x 3,650 hours) and would result in an annual cost savings, at three cents per KWH, of $930.

In the main corridors surrounding the main lobby there are 10-foot-high luminous ceilings that provide 70 fc. This level is excessively high and should be reduced by half to a more than adequate level of 35 fc. This could be accomplished by merely switching off the proper circuits at the panel board and revising some of the circuitry at the lighting fixtures. This would be necessary to balance the light output above the luminous ceiling. This would cost about $1,500. The energy savings would be 275,940 KWH per year (31.5KW x 8,760 hours [24 hours a day]) and would result in a savings of $8,278 per year at three cents per KWH.

f. Pier Corridors Light Reduction. The pier corridors are adequately lighted with an average of 30 fc and should not be cut back. The exceptions are the corridors for Piers C and E which have around 50 to 60 fc and should be reduced by half. These lighting circuits could be switched off at the panel board with some circuit revisions at the lights for a cost of about $600. The energy savings would be 105,120 KWH per year (12KW x 8,760 hours) and would result in a savings of $3,154 per year, at three cents per KWH.

The north and south concourse corridors both had their lights off during the day and had more than adequate lighting levels due to the large amount of glass area. This practice should be continued with the lights turned on at night. A time switch should be installed (if not already) to ensure that these lights are turned on at night. This energy savings would be 36,135KWH (9.9KW x 3,650 hours) and, at three cents per KWH, would result in a yearly savings of $1,084.

g. Baggage Areas. These areas have about 40 to 50 fc and should remain as-is. This lighting level is necessary to provide easy handling of baggage and reading of tags.

h. North Terminal Lamp Change. In the new North Terminal building and Piers H and I the use of 35-watt lamps will reduce the energy consumption by 12.5 per cent for a savings of about 989,880KWH (113KWH x 8,760 hours). At three cents per KWH this results in a cost savings of $29,696 per year.

Once construction is completed an on-site inspection could be made to determine which fixtures could be turned off during the day for an added energy savings.

i. Summary. An added advantage of turning off fixtures during the day is that it doubles the life of the ballasts and increases lamp life resulting in added savings in replacement costs.

Maintenance of lighting fixtures is very important in achieving high lighting efficiency. An inspection of the terminals revealed about 30 per cent of the lamps were burned out, indicating too long a period between group relamping or that lamps were replaced only after a certain number had burned out. Fluorescent lamps lose efficiency toward the end of their life, producing far fewer lumens but at the same power consumption. Therefore, group relamping should be done around every 18,000 hours for the average lamp life of 20,000 hours for fluorescent lamps.

Energy and cost savings for the entire airport complex are are summarized in Table 5.1.1.

Table 5.1.1

Annual Energy and Cost Savings

Area	Energy Savings (KWH per year)	Cost Savings per year*
Change lamps (North Terminal)	989,880	$29,696
Change lamps (South and Central)	832,200	24,966
South Terminal	186,150	5,584
Central Terminal	306,965	9,208
Pier Corridors	141,255	4,238
Total	2,456,450	$73,692

*These costs do not include the installation costs. At $0.03 per KWH, the installation cost in most cases is repaid in less than a single year.

5.2 Heating, Ventilating and Air Conditioning

a. Existing Steam Boilers. There are three I. W. Murray Company water tube steam boilers located at the South Terminal boiler room. These boilers are rated at 7,250 pounds per hour steam output (about seven million BTUH) at 125 PSIG. The boilers were originally installed in 1962.

The Operations Engineer indicated that one boiler is always secured and the majority of the time only one is required to be on line. These boilers provide heating to the South and Central Terminals as well as Piers B, C, D, E, F and FF and Rotunda A. About 35 per cent of the steam output was used by Host Kitchens at the Central and South Terminals.

The master plan of the airport indicates that these boilers will be removed in the future when the Central Plant presently under construction is completed and the conversion of mechanical equipment is made at the various mechanical rooms to utilize the high temperature hot water (HTHW) from the new Central Plant.

Because of this planned removal, capital improvements such as installation of economizers in the boiler flue, automatic combustion control equipment and instrumention are not recommended.

The boilers can be kept at maximum efficiency with good maintenance programs. Periodic checks of flue gas for carbon dioxide content and stack temperature will give an indication of boiler operating efficiency.

b. Check and Calibrate Controls. As part of the regular maintenance program the various temperature control devices should be checked for proper operation so that spaces are not over-heated or over-cooled. Automatic dampers should be checked for leakage and proper control operation. Room thermostats for interior zones should be set at 78°F. to reduce cooling requirements. Room thermostats for perimeter zones should be set at 75°F. to minimize both heating and cooling loads. On heating-only systems, room thermostats should be set between 68°F. and 70°F. to reduce heating loads.

c. Program Start-Stop. The entire airport passenger terminal complex will have 363 fans totaling 5,564 motor horsepower by the completion of the present expansion program (see Table 5.2.1). The new garage ventilation fans will be on automatic on-off control, operating through carbon monoxide monitoring systems. These garage ventilation fans, including supply and exhaust, will be a total of 94 with 864 motor horsepower. The remaining 274 motors totaling 4,700 horsepower are on manual control primarily and run continuously.

The airport terminal's traffic pattern is cyclical and would therefore provide an opportunity for saving energy by shutting off some of the fans during low-load periods. A reduction of only one hour per day of operation of the non-garage vent motors would save 3,500KWH per day and 1,278,050KWH per year. At three cents per KWH the annual savings would amount to $38,340.

The existing motor controls for the fans are by manual means at motor control centers in the Central and South Terminals and piers, at the HVAC control panel in the east and west mechanical rooms of the North Terminal, and in the ground-level pump room in Piers H and I. A pre-programmed motor shut-down schedule can be established to provide an automatic means of turning motors off and on. The cost of such a system for all of the fan motors is estimated as follows:

Controller @ $600 x 274	$164,400
Wiring @ $400 x 274	109,600
Control Processor	60,000
Processor System Wiring	
(4,000 feet x $10)	40,000
Miscellaneous overhead and profit	73,800
Total cost in 1977	$447,800

Table 5.2.1

Fan Tabulation

Terminal	Year	Supply Fan Number	Supply Fan CFM	Supply Fan HP	Return/Exhaust Fan Number	Return/Exhaust Fan CFM	Return/Exhaust Fan HP
Central Connectors	1952	1	5,000	2	1	8,500	2
Central Main Bldg.	1952	12	109,400	50	22	154,225	56
Pier E	1958	3	57,700	48	11	52,830	23
Pier B	1959	2	31,400	12	8	30,420	8
South	1961	12	703,000	590	15	341,310	186
Pier FF	1965	2	51,380	40	3	51,960	29
North	1977	10	684,100	1,510	36	917,485	652
Piers H & I	1977	10	326,105	590	18	318,075	305
Garage Central Plant	1977	5	86,500	85	4	50,000	40
Garage New Addition	1977	38	130,040	176	26	74,630	20
Garage Vent		31	1,362,500	500	24	243,500	43
Garage Exist.Remodel	1978	20	43,100	54	6	36,330	10
Garage Vent		18	826,500	300	21	168,000	21
Rotunda A	1970	3	119,700	202	2	7,400	10
Total		171	4,536,425	4,159	197	2,454,665	1,405

The cost of such a system could be recovered in about 12 years. If this system is installed as part of a master plan control system for the entire airport, the payback period would be reduced. It would be highly appropriate to incorporate such a system at that time.

In addition to the operation of the fan motors, the operation of the pumps and new electric chillers (3,000HP each) could be analyzed to reduce running time. Because of the complex nature of overlapping environmental and operational load conditions, a computer simulation would be required to establish the optimum operating hours and associated cost savings or penalties in reducing operating hours of the chillers.

d. Economizer Cycle. The airport is located in the San Francisco area which has a temperate climate. This provides the benefit of available cool air for air conditioning use during long periods throughout the year. The annual average number of hours when "free" cooling is available (outside air below 55°F.) are shown in Table 5.2.2.

Table 5.2.2

Annual Average Hours of Natural Cooling

January	651	May	341	September	210
February	504	June	240	October	310
March	496	July	217	November	420
April	420	August	248	December	589

Total: 4,646 hours

This is 53 per cent of the total hours in the year. Most of the existing HVAC systems in the Central and South Terminals and piers have provisions for utilizing outside air for cooling. This is because the majority of those systems are not presently provided with mechanical refrigeration equipment.

The new North Terminal and Piers H and I, however, have a fixed-mix system using a constant percentage of outside air. These systems were designed based on criteria established six or seven years ago when the advantage of reducing dirt loading (via outside air) exceeded the requirements for energy conservation. With continued escalation of fuel costs, the HVAC system for the new North Terminal and Piers H and I as well as future renovation of the South and Central Terminals should be reconsidered. A rough estimate of energy savings is as follows:

Average mixed air temperature = 70^{O}F.
Designed cold duct temperature = 55^{O}F.
Average temperature differential = 15^{O}F.
Cooling air at 80 per cent of design CFM - 808,160 cooling
BTUH required = 1.08 x 808,160 x 15^{O}F. = 13,092,256 BTU/Hr.
For 4,646 hours operation, savings in energy =
13,092,256 x 4,646 = 60,826 million BTU's.
With an estimated system COP (coefficient of performance) of 4:
Input energy savings = 60,826/4 x 3,412 = 4,456,770 KWH.
Cost savings at three cents per KWH = $133,703 per year.

The net cost savings will have to be reduced by the amount of energy required to heat the air in the hot duct. Again, the actual energy savings by converting to 100 per cent outside air system can be best simulated by the use of a computer program. It should be clear, however, that the potential is great for conserving energy.

e. Ceiling Fans. Ceiling fans can provide positive, gentle air circulation without drafts. Widely used for years in commercial buildings, these simple devices are experiencing a come-back with the high cost of heating and cooling. Not only do they increase comfort at higher temperatures (like driving in a convertible), but at low speeds they can also cut heating costs up to 30 per cent by minimizing temperature stratification in high-bay buildings.

Heat stratification exists, in varying degrees, in all structures with ceiling heights in excess of 12 feet. It results from warm air rising toward and being trapped at the ceiling. This warm air can be as much as 10^{O} to 25^{O}F. warmer than the air at floor level and will eventually be lost due to heat losses through the roof and upper wall construction.

Ceiling fans can be used to recirculate the hot stratified air down into the working area, thus developing a more uniform temperature throughout the structure. Reclaiming hot stratified air will significantly reduce both the load on the heating system and annual heating costs. In addition, the constant recirculation of warm air throughout the facility will eliminate "cold spots" which are one of the major causes of complaints.

At the airport, ceiling fans could go a long way in eliminating the need for air cooling. The loads are cyclic. Many people crowd into one area for a short time creating a cooling demand. Thermostatically-controlled fans could gradually increase the air movement (as the temperature rises) creating a comfortable environment without air cooling.

If the cooling loads remain high for an extended period of time and the temperature rises above a comfortable threshold (even with the fans operating), then the air conditioning system would automatically activate. Once the load diminishes (the plane leaves), the excess heat will dissipate (be lost) or be absorbed by the thermal mass for storage and latter use (see Section 4.7.c, Thermal Mass).

f. Conversion to Variable Volume System. All of the existing and new terminals under construction use the constant volume air system for cooling, heating and ventilation. The air quantities delivered are based on block building peak loads for cooling. During much of the time, however, the building is operating at less than peak load and air quantities can be reduced without sacrificing comfort conditions. The reduction of air quantities during non-peak conditions will save energy by saving motor horsepower with the use of proper variable volume control devices. This also saves energy in cooling a smaller quantity of supply air and reheating air at some perimeter zones.

Conversion to a variable air volume (VAV) system is not recommended for the Central and South Terminals and the associated piers. The new North Terminal, Piers H and I and Rotunda A are more likely candidates for conversion to a VAV system. These are presently high-velocity, double-duct, constant-volume air systems. They can be converted to VAV systems by installing inlet vanes in the supply and return air fans, abandoning the hot air ducts, adding terminal reheat coils at perimeter zones and adding new control air valves and system static pressure controls. The initial investment for such a conversion is very high and it is doubtful that the payback period would be economically satisfactory. Such a VAV system, however, would definitely be recommended for any new building addition or terminal renovation.

With the present design, the double-duct systems in the North Terminal, Piers H and I and Rotunda A utilize bypasses around the supply fans to provide temporary balancing of fan operation. The bypass air totals about 170,000 CFM or 15 per cent of the fan delivery. This bypass air would not be necessary with VAV systems and the savings would be 849 HP ($2200 - 2200 \times [.85/1.00]^3$). The actual savings would be less because of system static pressure requirements. Assuming that 400 HP could be saved, the annual savings in energy could be $78,419 (400 HP x 8,760 x .746 = 2,613,914KWH x three cents per KWH).

g. <u>Reduction of Static Pressure Losses</u>. The Central and South Terminals with the associated piers have low to medium pressure (3.5-inch S.P.) fan systems and use minimum efficiency air filters with low air pressure loss. No change in these systems is recommended.

The air systems in the North Terminal, Piers H and I and Rotunda A have high velocity duct systems ranging from 6.5-inch to 11-inch static pressure loss. Such high pressure systems are energy-intensive. This can be remedied by reducing the system air quantity and reducing the mechanical losses through the air filters and coils.

The air quantities in some areas are maintained at 1.5 CFM per square foot due to airport tenant improvement guide recommendations. Such air quantity may not be necessary for maintaining comfort conditions and can be reduced. A 10 per cent reduction in the air system would reduce the static pressure by 19 per cent and the motor horsepower by 35 per cent, or about 800 horsepower, with cost savings similar to that calculated for a VAV system, i.e., about $80,000 per year.

The second remedy is to reduce static pressure loss through the air filters. Present configuration includes a four-inch prefilter, an 85 per cent efficient bag filter and a carbon filter. The total pressure loss through this assembly is estimated at 1.85 inches of water. Reduction of the air pressure loss can be made by (1.) deleting the prefilter with resulting pressure loss of 1.35-inches S.P. and increasing filter maintenance cost; (2.) deleting carbon filter and prefilter with resulting pressure loss of one-inch S.P., but increase filter maintenance and lower air quality; or (3.) downgrade the bag filter to 35 per cent efficiency and deleting the prefilter with resultant pressure loss of one-inch S.P., but increased maintenance cost. Because of the number

of combinations in filter arrangements and the difficulty in accurately predicting maintenance cost or air quality, some subjective criteria would be needed to establish the design air filtration requirements. Assuming that (2.) is selected, the reduction of pressure loss from 1.85-inch to one-inch S.P. would result in fan horsepower savings of about 274 HP ($2200 - 2200 \times [9.15/10]^{3/2}$), a power savings of 12.5 per cent equal to about $53,700 per year at three cents per KWH.

h. Heat Recovery Devices on High Temperature Hot Water Boilers

Commercially available economizer heating coils can be installed in the boiler exhaust flues to capture part of the waste heat escaping up the boiler stack. The potential energy recovery is described in Section 5.3, Plumbing. The estimated practical recovery is calculated as follows:

Boiler flue gas = 27,275 pounds per hour per boiler
530°F.
0.245 BTU/pound/°F.
Temperature extraction = 530°F. - 350°F. = 180°F.
Heat extraction: 180°F. x 27,275 pounds per hour x .245
= 1,202,827 BTUH per boiler.

With 1380 hours of equivalent full load operation per year, energy saved:
$1380 \times 1{,}202 \times 10^6 = 1658.76 \times 10^6$ BTU = 16,587 therms
@ 21.5¢/therm = $3,566 per year.

Installation cost per boiler for the economizer is estimated at $45,000.

i. <u>High Efficiency Motors</u>. Motors with 10 per cent higher efficiency are now commercially available for smaller-size horsepower motors. With escalating electrical costs, the estimated 15 to 20 per cent premium of these motors could be paid back in a very short time. The higher efficiency motors would also run cooler and have a longer motor life.

j. <u>Exhaust Air Quantity</u>. The new garage addition and the remodeled existing garage will have a total supply air quantity of 2,189,000 CFM and exhaust air quantity (for the first level only) of 411,500 CFM. The present design requires the exhaust fans to run continuously and the supply fans are controlled by the carbon monoxide monitoring system which can turn on the supply fans in sequence according to the measured carbon

In Section 1105 of the 1976 Uniform Building Code, the ventilation requirements for enclosed garages have been revised to permit automatic control of ventilation air by carbon monoxide-sensing devices to maintain a maximum average concentration not greater than 50 ppm during any eight-hour period, and a maximum concentration not greater than 200 ppm for a one-hour period. With a strong prevailing westerly wind and the cyclical nature of garage traffic operations, the first level exhaust fans can be turned off perhaps 50 per cent of the time. This would save 280,320KWH per year (64HP x 0.5 x 8,760 KWH), equivalent to $8,409 in savings.

k. <u>Central Control and Monitoring System</u>. In Section 5.2.c on program start-stop of HVAC equipment it was shown that the capital cost can be recovered in about 12 years.

The next step in reducing electrical energy consumption and cost would be to install an integrated demand controller which will continuously monitor the difference between a generated "ideal energy rate" and an "actual energy rate."

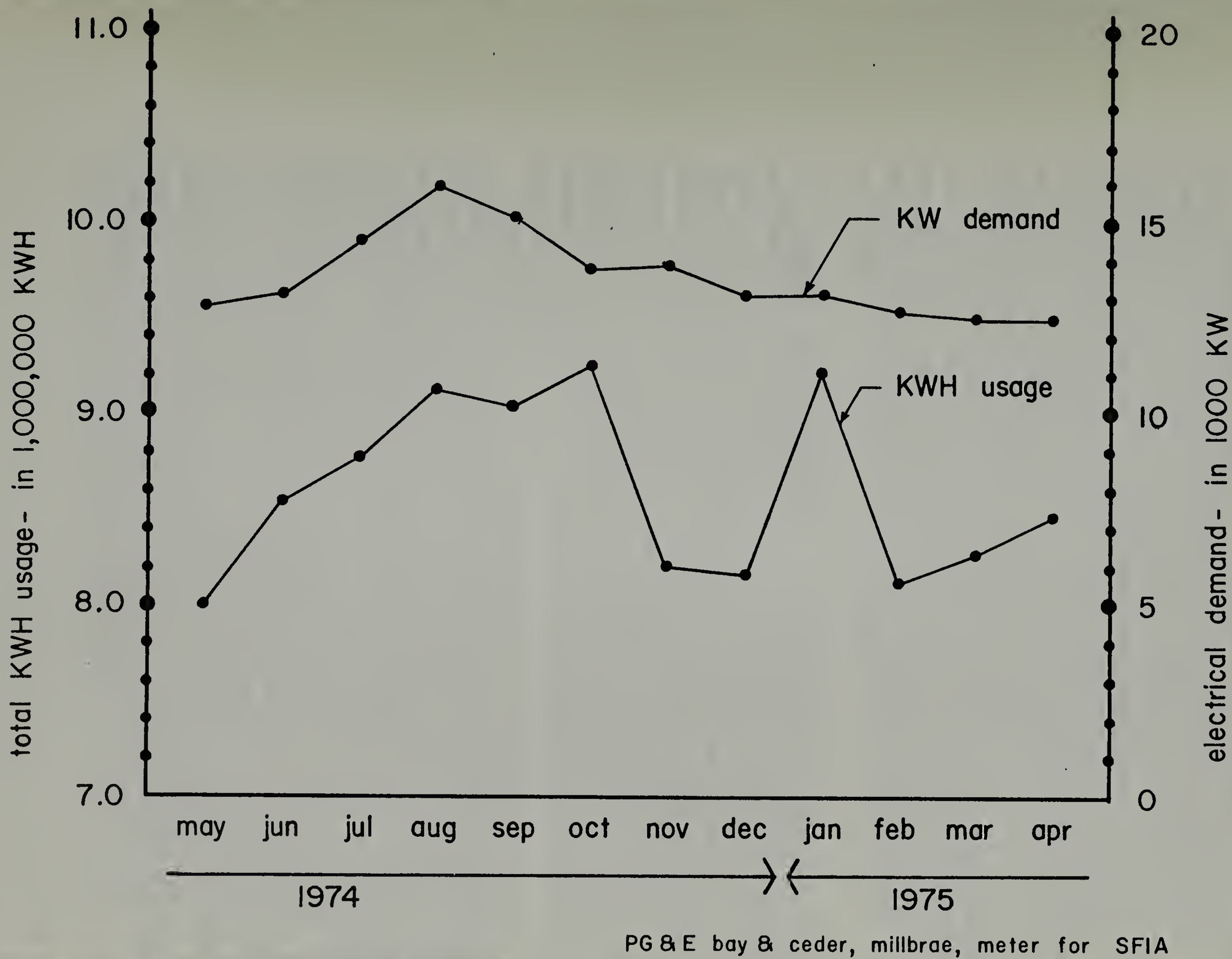
The controller should incorporate multi-output circuits terminating in solid state control program cards for each of the building supply and return/exhaust fans, pumps and other electrical load devices to be considered for load shedding. Programming should be arranged by pre-determined priority of operation at various areas of the airport so as not to deprive the building occupants of necessary support facilities.

The plot of electrical demand for the period from May 1974 to April 1975 (taken from P G and E's Millbrae substation records) shows a distinctive peak which is not coincident with power usage peaks. This peaking characteristic provides potential for saving electrical cost under the present methods of calculating electrical charge to the airport. A reduction in the demand peak will reduce electrical costs substantially. The exact cost savings will depend on the demand level to be established by the priority of services required.

The establishment of this priority to reduce electrical demand peaks can be done on a basis similar to the "zero-base budgeting" method currently used by the federal government and others. A "Zero Base Energy Budget" (ZBEB) can be set up for each area of operation at the airport terminal complex. This ZBEB will form the basis for the operational priority and be programmed into the load shedding controllers of the demand control system.

The present estimate of such a demand control system for the terminal complex would be about one million dollars. If the programmed start-stop of fans described before was added to this system, the combined cost would be around $1,250,000.

To further increase the efficiency of building mechanical and electrical systems, a master central control system can be established at a central location in the complex. This system will take over the functions of HVAC systems control and monitoring, provide maintenance program functions, program start-stop of fans and motors, load-shedding to reduce electrical demand peak and also be able to supervise the fire alarm system, security system, guard tour route check and closed circuit television. The cost of such a system would be around three million dollars, not including the cost of the building. The benefits of such a system include lower maintenance personnel costs, higher operation efficiency of equipment, lower energy consumption, lower energy cost, more accurate accounting of system performance, easier trouble-shooting of malfunctions and increased reliability of system operations. The draw-backs are high installation cost, higher initial personnel cost in training, and a more complex system to maintain.



san francisco international airport

solar feasibility study

fig. 5.2.1

annual electrical demand and usage

5.3 Plumbing

a. Temperature Reduction. At the new North Terminal and Piers H and I now under construction, the domestic hot water supply temperature is already set at 105°F. which is a desirable temperature from an energy conservation standpoint. In the Central and South Terminals and Rotunda A, the present domestic hot water supply is set at 140°F. This setting should be reduced to 105°F. to conserve energy. No capital expenditure would be required. The temperature re-set can be accomplished by airport engineering or maintenance service personnel.

It is recommended and anticipated that future remodeled piers and terminals would have domestic hot water supply temperatures set at 105°F. This temperature setting not only conserves energy by reducing heat loss in the system, but also would be more compatible with a solar heating system.

b. Preheat With Waste Heat. A scavenger-type shell and tube exchanger can be installed in the condensate return line with the domestic water in the tube bundle and the condensate in the shell. The draw-back to this method is that the present boiler room at the South Terminal is located a long way from the existing domestic water heaters at Rotunda A, the Central Terminal and Piers B, C, D, E, F and FF. The second factor against this scheme is the planned removal of the steam boilers within the near future. These two negative factors lead to the conclusion that this method would be uneconomical.

The flue gas waste heat from the new central plant boilers, however, can be reclaimed for both domestic water and space hot water heating or preheating. The waste heat from these new boilers will vary between 20 and 40 per cent of the total heat input. With a total future capacity of 128 million BTU/hour input, the waste heat potential would be from 25.6 million BTU/hour to 51.2 million BTU/hour. Due to the inefficiencies of heat reclaim systems and the additional power input required to extract the waste heat, the net maximum heat capacity recoverable may be about 25 per cent of the potential. Even this fraction could save 6,400 to 12,800 CFH of natural gas. Taking the lower figure of 6,400 CFH and assuming an average load equal to 15 per cent full load heating, the savings would amount to 8.4 million cubic feet of natural gas with $18,080 per year at 21.56 cents per therm (per P G and E Schedule G-50, April 1977).

The description above indicates the energy saving potential. A detailed cost study should be made to evaluate the actual useable energy savings and dollar savings on a life-cycle cost basis.

c. Water Conservation. Reduction in water usage has come to the forefront recently because of the current two-year drought situation in California. It should be obvious that reducing water usage also saves energy in pumping, purifying, heating and treating it.

Restriction of water usage can be achieved by:

(1.) Installing flow restrictors at each faucet.

(2.) Partially closing the shut-off valve (should be done only on a temporary basis).

(3.) Installing automatic closing faucets.

(4.) Reducing the flush tank volume to a minimum (e.g., use three-gallon size flush tanks).

(5.) Activate the flush valve of urinals only on a periodic basis.

The Office of the State Architect is investigating the use of vacuum toilets which would reduce water required from six gallons to two quarts per flush. The vacuum toilet system would require a completely new plumbing system with presently prohibitive installation cost.

2